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A PROGRAM OF SOLAR RESEARCH.[1]

BY GEORGE E. HALE

In an article on "Solar Research at the Yerkes Observatory"[2] I have given, in outline, a program of solar investigations prepared several years ago. Some of the investigations included in this program were carried out at the Yerkes Observatory, and others are still in progress there. As explained in another paper,[3] it was found that the solar spectrograph attached to the 40-inch telescope was of insufficient focal length for satisfactory photographic work on the spectra of sun-spots, and accordingly this work was postponed, and has recently been taken up at the Solar Observatory. For similar reasons it was found to be advantageous to delay other investigations until the completion of the Snow telescope. We are finally in a position, however, to attack the whole question seriously. I have therefore thought it might be of interest to publish the revised program of solar research which we are putting into operation on Mount Wilson.

In preparing this program, two principal purposes have been considered: (1) the study of the Sun as a typical star, with special reference to stellar evolution; (2) the study of the Sun as the central body

[1] *Contributions from the Solar Observatory*, No. 3.

[2] *Astrophysical Journal*, 16, 211, 1902.

[3] *Contributions from the Solar Observatory*, No. 5: "Photographic Observations of the Spectra of Sun-Spots."

of the solar system, with special reference to the relationship between solar and terrestrial phenomena.

The proposed investigations include:

I. DIRECT PHOTOGRAPHY

a) Daily photographs of the Sun on a scale of 6.7 inches (17 cm) to the diameter, for comparison with spectroheliograph plates.

b) Large-scale photographs of spots and other regions, for the study of details.

II. PHOTOGRAPHIC STUDIES OF THE SOLAR ATMOSPHERE WITH THE SPECTROHELIOGRAPH

a) Daily photographs of the Sun with the lines:
   (1) H_1, showing the calcium flocculi at low level.
   (2) H_2, showing the calcium flocculi at higher level.
   (3) H_2, showing the calcium flocculi at higher level and the prominences (composite photographs, with separate exposures for flocculi and prominences).
   (4) $H\delta$, showing the hydrogen flocculi.
   (5) Other dark lines, as may prove feasible, showing the flocculi of the corresponding elements.[1]

b) Measurement and discussion of the above photographs, involving:
   (1) Determination of the area of the flocculi and their distribution in heliographic latitude and longitude. These results will give a measure of the relative activity of different elements in various regions of the solar surface; furnish the means of answering certain questions regarding the relationship of flocculi to spots, such as the time of first appearance, relative position on the disk, etc.; and serve for comparison with meteorological and magnetic records.
   (2) Measurement of the heliocentric position of points in the flocculi that can be identified on several successive photographs, to determine the law of the solar rotation for the corresponding elements.
   (3) Determination of the position, area, and brightness of eruptive phenomena, to find whether they are related to other phenomena of flocculi or spots, to possible changes in the

[1] λ 4045, showing the iron flocculi, is now used daily.

absorption of the solar atmosphere, and to auroras and magnetic storms.

(4) Measurement of the area and brightness of the neutral or bright regions near sun-spots, on photographs of the hydrogen flocculi, for comparison with other phenomena, such as the velocity of ascending and descending currents of calcium vapor, the intensity of radiation (for given wave-lengths) of the spots and neighboring regions, etc.

(5) Study of the motion of the high-level calcium vapor, especially in flocculi overhanging sun-spots, to determine the direction and velocity of horizontal currents.

(6) Measurement of the position and area of prominences, and study of their relationship to solar and terrestrial phenomena.

c) Special studies with spectroheliographs of suitable dispersion, involving the use of various dark lines (including enhanced lines) and of lines affected in spots; simultaneous photographs of eruptions on the disk in different lines; comparative studies of quiescent and eruptive prominences with the hydrogen and calcium lines, etc.

III. SPECTROSCOPIC INVESTIGATIONS

a) Daily photographs of the spectra of spots, region $H\alpha$ to $H\beta$, for the determination of intensities and the identification of lines that are widened or otherwise affected.[1]

b) Photographs of the H (or K) line, with high dispersion, on successive sections of the disk, to give the radial velocity of the calcium vapor in the flocculi, chromosphere, and prominences.

c) Measurements with the bolometer of the relative radiation, corresponding to various wave-lengths, of the sun-spots, faculae, and photosphere; and bolographs of spot spectra.

d) Spectrographic measurements of the solar rotation, to determine the law of rotation with the lines of various elements, and to detect possible changes in the rotation period. (See also II, *b*), 2.)

e) Miscellaneous investigations, as opportunity may offer, of the

[1] These photographs may also serve to record such exceptional phenomena as the remarkable disturbance of the reversing layer described in a previous paper (*Astrophysical Journal*, **16**, 220, 1902).

spectrum of the chromosphere; the pressure in the solar atmosphere, etc.

IV. STUDIES OF THE TOTAL SOLAR RADIATION

a) Frequent determinations of the total solar radiation, involving measures with the pyrheliometer at various altitudes of the Sun, and simultaneous bolographic records to give the absorption of the Earth's atmosphere.

b) Frequent determinations of the absorption of the solar atmosphere for light of various wave-lengths, to detect any possible changes in absorption that might account for observed changes in the total radiation.

c) Occasional supplementary observations on Mount San Antonio, (24½ miles = 39.4 km from Mount Wilson) at an altitude of 10,100 feet (3,050 m).

d) A comparative study of different types of pyrheliometers.

V. LABORATORY INVESTIGATIONS

a) A study of the lines affected in sun-spots under various conditions of temperature, pressure, etc.

b) Determinations of the pressure-shifts of certain solar lines.

c) Other similar investigations.

With a few exceptions, these investigations are now in progress at the Solar Observatory. Direct photographs of the Sun are taken daily, but large-scale photographs of details have not yet been started. The daily spectroheliograph routine includes H_1, H_2, $H\delta$, and λ 4045 (*Fe*) photographs of the disk, and H_2 (composite) photographs of the flocculi and prominences, all on a scale of 6.7 inches to the Sun's diameter. (See *Contribution* No. 7.) Special studies with the spectroheliograph are also in progress. An account of the work on spot spectra and on the motion of the calcium vapor may be found in *Contributions* Nos. 5 and 6. Special apparatus for the spectrographic study of the solar rotation has been nearly completed in our instrument shop. The study of the solar radiation has so far been confined to the investigations of the Smithsonian Expedition (June–November 1905), but arrangements have been made to continue this work next year. In the laboratory an investigation has been undertaken of the effect of a magnetic field on lines that are widened in sun-spots.

There are many solar investigations not included in this program which offer important returns to careful observers. In visual observations attention may well be directed to such matters as the brightness of the inner extremities of the penumbral filaments; the relative width of these filaments in large and small spots; the evidence for and against cyclonic motion in spots; the changes in the peculiar patterns frequently assumed by the photospheric granules; the character of the granulation in the faculæ, etc. Large-scale photographs, like those of M. Janssen, may also be used in the study of such questions, but the most minute phenomena can be observed only visually. The chromosphere and prominences offer an excellent field for the visual study of details, in addition to the statistical studies of the Italian spectroscopists and other observers, which should be continued and extended. At times of good definition, the spectrum of the chromosphere will richly repay observation with powerful instruments. The same may be said of spot spectra, where many observers can find profitable employment.

The above investigations are mentioned merely as examples of the innumerable opportunities open in solar research. As I hope to show at some future time, the amateur, even if his instrumental equipment be a very modest one, may do work of the highest value, if he will plan it intelligently. A careful consideration of the requirements of promising researches, and a willingness to co-operate with others, should enable any observer to contribute in an important way to the progress of solar physics.

MOUNT WILSON,
December 1905.

SOME TESTS OF THE SNOW TELESCOPE[1]

BY GEORGE E. HALE

In *Contributions from the Solar Observatory*, No. 2, I have given a brief description of the Snow telescope and the house in which it is mounted on Mount Wilson. At the time that paper was written the telescope was not yet in working order, and it remained to be determined whether it would prove capable of giving the results expected from it. I am glad to say that it has since been completed and successfully used in a variety of work. It is believed that an account of the experience so far gained with this telescope may be of service to others who may intend to use similar instruments.

The cœlostat and second mirror are shown in Plate I, a view taken from within the sliding shelter which covers these parts of the instrument when not in use. The cœlostat mirror is 30 inches (76 cm) in diameter, and the second (plane) mirror, which sends the beam from the cœlostat to the concave mirror in the north end of the telescope house, has a diameter of 24 inches (61 cm). The second mirror can be moved along rails, so as to receive the reflected beam from objects at different declinations. The cœlostat and second mirror stand on a stone pier 29 feet (8.8 m) high at its south end and 25 feet (7.6 m) high at its north end. A house, of steel construction covered with canvas louvres, surrounds the pier and affords space in the extension toward the north for the concave mirrors and the spectroheliographs and spectroscopes. The concave mirror, shown in Plate II, has an aperture of 24 inches and a focal length of 60 feet (18.3 m). A second concave mirror of the same aperture and of 143 feet (43.6 m) focal length is under construction in our optical shop, and will soon be mounted in the long extension of the house which lies beyond the canvas partition now temporarily in place near the 60-foot mirror.[2]

[1] *Contribution from the Solar Observatory*, No. 4.

[2] For a plan and elevation of the Snow telescope house, together with photographs showing its manner of construction, and a further account of the instrument, see *Contributions from the Solar Observatory*, No. 2, and the *Report of the Director of the Solar Observatory for the Year Ending September 30, 1905*.

PLATE I

Coelostat and Second Mirror of Snow Telescope

PLATE II

Concave Mirror of Snow Telescope

In the preliminary tests of the Snow telescope at the Yerkes Observatory, the results were rather disappointing, though good images were occasionally obtained. It was evident that difficulty might be expected from the distortion of the mirrors by the Sun's heat, and in the first experiments on Mount Wilson this expectation was realized. Soon after the exposure of the mirrors to the Sun it was seen that the focal length was increasing, and, as the focus changed, evidence of the astigmatism of the mirrors made itself apparent in the appearance of the image inside and outside the focal plane. Since the change of focus amounted in some cases to as much as 12 inches (30.4 cm), and since the astigmatism under such circumstances was very marked, it was feared that great difficulty would be experienced in the use of the telescope, particularly as the focus at opposite limbs of the Sun on one occasion differed by as much as 3 inches (7.6 cm). The changes of focal length at different times did not seem to be the same, even for equal altitudes of the Sun. This was soon traced to the change in the amount of heat absorbed by the mirror as the silver film deteriorated in use. Another variable, as subsequent experiments proved, was introduced by the strength of the wind and the temperature of the air blown across the mirror surface. On a day with a cool breeze the focus changed less than on a day with no wind. Naturally enough, the height of the Sun above the horizon proved to be a very important factor, so that the focus changed much more rapidly near noon than early in the morning.

From the outset, the advantages of observing the Sun during the early morning hours had been apparent. In view of the difficulties that were being experienced, this point was again carefully investigated, and it was soon found that with the Snow telescope the finest definition is to be expected about one hour after sunrise. At this time the mountain is but little heated, and the atmospheric absorption reduces the intensity of the solar radiation to such a degree that the mirrors change their figure slowly. If the mirrors are shielded from sunlight between exposures of photographs, and if the exposure time is made as short as possible, excellent results can be obtained

during a period of about an hour in the early morning, and usually during a similar period not long before sunset.

It must be understood that the precautions mentioned are necessary only when it is desired to secure the finest possible definition of the solar image. When such precautions are used, the average photographs taken during the summer in the early morning with the Snow telescope and temporary spectroheliograph are but little inferior to the best photographs, secured on only a few days in the year, with the 40-inch Yerkes telescope and the Rumford spectroheliograph. The best photographs taken on Mount Wilson are distinctly superior to the best ever secured by Mr. Ellerman and myself with the 40-inch telescope. Unless these points were made clear, it might be supposed that no work could be done with the Snow telescope except under the conditions stated. As a matter of fact, however, very fair photographs can be obtained with the spectroheliograph at almost any time during a cool day, and in the early morning and late afternoon hours of a hot day without wind. It is only necessary to arrange the daily program of observations so that the spectroheliograph, which requires the finest definition, is used during the period when the seeing is best. Photographic work on the spectra of sun-spots follows, and after this is completed the conditions are entirely satisfactory for various other observations, such as bolographic work on the absorption of the solar atmosphere, etc.

The photographs reproduced in Plate III will give an idea of the results obtained with the Snow telescope. The spectroheliograph employed was put together for temporary use pending the completion of the permanent instrument. The only prisms available were some that had proved unsuitable (because of poor definition) for the Bruce spectrograph, and the slits were taken from old instruments. The optical train was mounted on a wooden platform, with cast-iron Λ-rails running on four steel balls resting on cast-iron V-rails attached to a wooden base. A small electric motor, belted to a pulley on the end of a long screw, provided the motive power. The screw was mounted on the wooden base, and passed through a nut attached to the platform. The numerous photographs obtained with this simple and inexpensive apparatus have served for a comparative study of the faculæ and the H_1 flocculi.

PLATE III

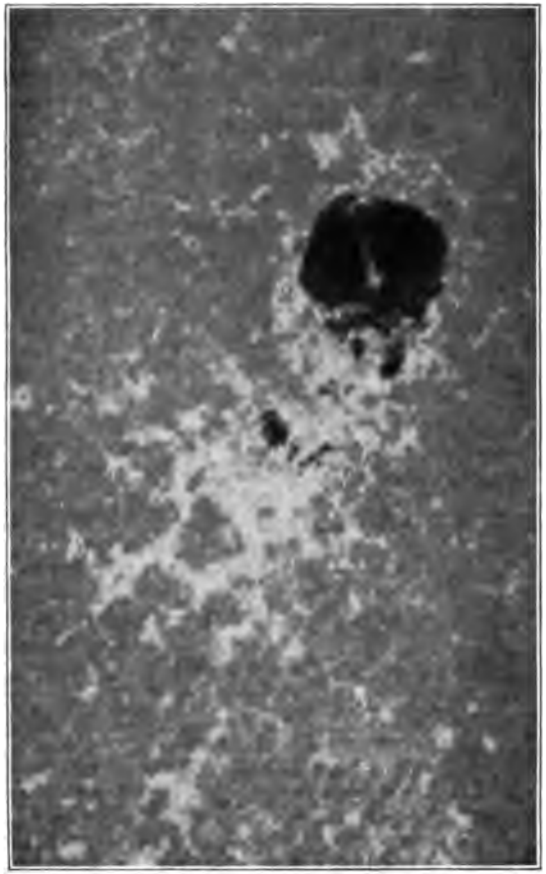


FIG. 1

July 17, 1905, 17^h 56^m. Low-Level Calcium Flocculi Slit Set on H_1 ($\lambda 3966$). Sun's Diameter = 0.28 meter.

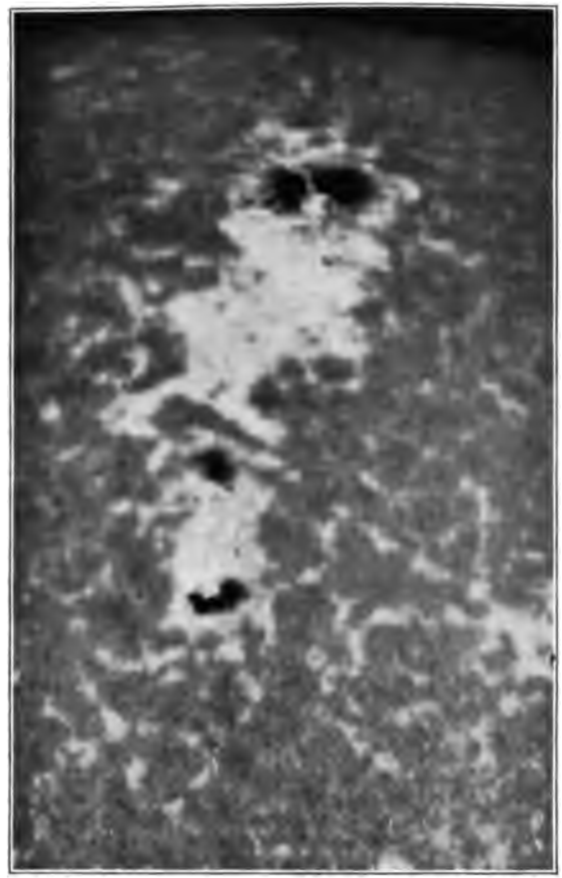


FIG. 2

July 20, 1905, 5^h 18^m. High-Level Calcium Flocculi. Slit set on H_2. Sun's Diameter = 0.28 meter.

The ventilated house provided for the Snow telescope has proved so satisfactory that it has not seemed necessary to make further experiments on the use of Langley's method of stirring the air along the path of the beam. It is usually found best to lower the inner canvas wall on the side of the house away from the Sun, leaving the canvas wall on the opposite side of the house in place, so that the heated air under the louvres may pass upward and out through the ventilated roof, instead of entering the house and disturbing the beam (see Plate II).

While fans have not been employed for stirring the air, they have nevertheless been used to advantage in blowing the mirrors, for the purpose of preventing a rapid change of figure. In the first experiments, a fan 4 feet in diameter, driven by an electric motor, was mounted at the south end of the cœlostat pier. Air from this fan was led to the cœlostat mirror and the second mirror through large canvas tubes. In these experiments the concave mirror did not receive a blast of air, as it was thought the effect could be detected sufficiently well if only the first and second mirrors were cooled in this way. As it was found that the focus could be varied through a considerable range by blowing the first two mirrors, arrangements have been made to cool all the mirrors in the same way. The small electric fans to be used for this purpose will be operated while the adjustments of the spectroheliograph are being made, and also between exposures, when the mirrors are also shielded from the Sun by an adjustable canvas screen.

Excellent definition is obtained at night with the Snow telescope, except when the mirrors have been exposed to the Sun for some hours during the afternoon. On such occasions the rapid change of figure during the early evening results in irregular distortions, as indicated by the multiple images sometimes observed. Without such previous exposure to the Sun, the images of the stars and of the Moon leave nothing to be desired. Nevertheless there is a considerable change of focal length during the night, but this would be inappreciable during short exposures, and during long exposures on stellar spectra it is only necessary to correct the focus by changing the position of the concave mirror from time to time.

It is to be hoped and expected that materials more suitable than glass can be obtained for the mirrors of telescopes which are to be used for solar work. Some preliminary tests of small mirrors of "Invar" (nickel-steel of the lowest coefficient of expansion), made by Hilger, indicate that this material can hardly be used, since it is too soft, in Professor Ritchey's opinion, to permit a large optical surface, even if once produced, to be kept well polished and free from scratches. It is probable that speculum metal could be used with a fair degree of success, since such a good conductor of heat would presumably act very differently from a poor conductor like glass. I am informed by Mr. Brashear that when speculum metal grating-plates are being figured, tests can be made very much sooner after polishing than is possible in the case of glass. This indicates that the figure is changed less by the heat produced by friction. Our attempts to produce disks of fused quartz have not yet been successful enough to demonstrate that mirrors can be made of this material.

From a mechanical standpoint the Snow telescope has proved to be completely successful. From an optical standpoint it has shown itself capable of giving results with the spectroheliograph superior to those obtained in our work with the 40-inch refractor. In view of the advantages it offers for many classes of astrophysical research, this telescope may now be considered to have passed the experimental stage, though the possibility of providing better material for the mirrors indicates that its optical performance will probably be considerably improved in the future.[1]

MOUNT WILSON, CALIFORNIA,
November 1905.

[1] For an account of recent work with the Snow telescope, see *Contributions*, Nos. 5, 6 and 7.

PHOTOGRAPHIC OBSERVATIONS OF THE SPECTRA OF SUN-SPOTS[1]

[1] *Contributions from the Solar Observatory*, No. 5.

By GEORGE E. HALE and WALTER S. ADAMS

INTRODUCTION

In the *Astrophysical Journal*, **16**, 217, 1902, an account is given of experiments in photographing the spectra of sun-spots made at the Yerkes Observatory in 1902. The spectrograph employed in this work was provided with collimator and camera of 3¼ inches (8.3 cm) aperture and 42½ inches (108 cm) focal length, and a plane grating having 20,000 lines to the inch (7,874 to the centimeter), used in the second spectrum. With the same spectrograph the more conspicuous of the widened lines had been photographed at the Kenwood Observatory some years previously, but the 2-inch (5 cm) solar image given by the 12-inch (30 cm) Kenwood refractor was found to be too small for satisfactory work. At the Yerkes Observatory the spectrograph was attached to the 40-inch (102 cm) telescope, and the 7-inch (18 cm) solar image proved to be large enough for all but the smallest spots. Many widened lines were photographically recorded, and the spot "bands" were partially resolved into lines, some of which were measured on the plates. The linear dispersion of the spectrograph, however, was quite insufficient to permit more than a small part of its resolving power to be realized photographically. For this reason the continuation of the work was deferred until a suitable spectrograph could be obtained. Since this instrument was to have a focal length of 18 feet (5.5 m), it could not be attached to the 40-inch telescope. For this reason it was decided to carry on the work with a long-focus horizontal telescope, then in process of construction in the instrument shop of the Yerkes Observatory.

INSTRUMENTS EMPLOYED

The experiments were resumed last August on Mount Wilson, with the aid of the Snow telescope, which gives a solar image 6.7 inches (17 cm) in diameter when the concave mirror of 24 inches

(61 cm) aperture and 60 feet (18.3 m) focal length is employed. In some of the experiments the image was enlarged to a scale of 16 inches (41 cm) to the Sun's diameter, by means of a Brashear concave amplifying lens; but while good results were obtained in this way, it was thought best to use the 6.7-inch image until the completion of the 24-inch mirror of 143 feet (45.7 m) focal length, which will give a 16-inch solar image without amplification.

The 6-inch (15 cm) objective of 18 feet (5.5 m) focal length for the Littrow (auto-collimating) spectrograph was under construction by the Zeiss Co., and no large grating was available. We were fortunate, however, in having the use of a 4-inch (10 cm) visual objective of 18 feet focal length, and a 4-inch grating, having 14,438 lines to the inch (5,672 to the cm), both belonging to the Yerkes Observatory. The slit of the Littrow spectrograph is mounted immediately below the photographic plate, to which the spectrum is returned by tilting the grating back through a very small angle. Light from the slit reflected toward the plate by the 4-inch objective is eliminated by pasting small pieces of paper to the inner surface of the lens. The plate-holder can be moved vertically by means of a rack and pinion, thus permitting several spectra to be photographed side by side on a single plate $3\frac{1}{4} \times 10$ inches (8.3×25.4 cm). As the distance from the center of the slit to the center of the spectrum is only $5\frac{3}{4}$ inches (14.6 cm), the astigmatism, which is at right angles to the direction of dispersion, is too small to be noticeable. The definition of the spectrograph is excellent visually, but in view of the comparatively long exposures required in the third-order spectrum, the present work has been done in the second order, where the linear dispersion is insufficient to secure complete photographic resolution. For this reason we hope to obtain better results when a larger objective and grating have been provided for the spectrograph.

At this point a few words may be said regarding the relative advantages of the visual and photographic methods of observing spot spectra. The visual method permits the finest details of the spectra to be seen, and thus renders possible the separation of close ines and the observation of such narrow reversals as Mitchell has recently recorded. Advantage can be taken of the moments of best

definition, and none of the various phases of rapidly changing eruptive phenomena need be lost, as they may be in photographic work where exposures of several minutes are required. For these reasons visual observations cannot be wholly supplanted by photography, in spite of the numerous advantages of the latter. These include:

1. The possibility of recording, during brief periods of fine definition, the entire spectrum of several spots, leaving the work of measurement and identification of the lines to be done at leisure.

2. The high degree of precision attainable in measurements o- the photographs, insuring correct identification of lines and the detection of small displacements caused by motion or pressure.

3. The ease of acquainting other observers, through the publication of photographs, with the exact nature of the results obtained, thus reducing the danger of such misunderstandings as are common in connection with visual work.

The plates used in our work are the Cramer Instantaneous Isochromatic, which have a maximum of sensitiveness at about λ 5600. With suitable exposure-time these plates cover the region from near the D lines into the blue-green. It would, of course, be possible to go farther to the red by extending the time of exposure sufficiently, but the curve of sensitiveness in this region is so steep that only a very small extent of spectrum would be properly exposed at any one time; and so it has seemed preferable to wait until specially sensitized plates become available for this work. The region which we include in our present discussion extends accordingly from λ 5000 to about λ 5850.

Table I gives in detail Mr. Adams' estimates of intensity and identifications with Rowland's solar lines for the widened lines upon ten of the plates, L 17 . . . . L 43. The individual determinations of intensity are given in order to show about what degree of accordance is to be expected among separate observations. As stated above, we have adopted Fowler's plan of estimating the spot lines in terms of Rowland's intensities, beginning with 0000, which represents a line at the limit of visibility, and going upward through 000, 00, 0, 1, etc. Intermediate intensities are denoted by a dash between the preceding and the following value: thus, 1–2 denotes a line whose intensity is

midway between 1 and 2 of Rowland's scale. In practice this system has proved very convenient. The spectrum of the spot has on either side the spectrum of the disk for comparison purposes, the intensities of the two having been made as nearly as possible the same through suitable exposure time. Accordingly, in examining the plates under a low-power microscope, the observer has in the same field of view with the spot spectrum a large number of lines of the comparison spectrum showing a wide range in intensity. The estimation of the intensities of the spot lines in terms of these then becomes very simple.

The first three columns of the table give Rowland's wave-lengths for the lines, the elements to which they are due, and their intensities in the Sun. The fourth column gives their intensities in the spots and is made up of the means of the succeeding columns. It is placed next to the column of Solar Intensities for convenience in comparison. The abbreviation "n. c." for "no change" denotes that the line is not affected.

The linear scale of the plates is very closely 1.5 tenth-meters to the millimeter.

The list below does not include lines for which the mean of the determinations does not show a change of intensity amounting to one-half of a division on Rowland's scale. It also omits a considerable number of "band-lines" in the region λ 5300 to λ 5600, which we are at present engaged in identifying, and shall publish later. The "band-lines" in the region λ 5000–λ 5200 are discussed elsewhere in this paper.

Visual determinations of the widened lines in this region of the spectrum have been published by many observers. The latest of these is that of W. M. Mitchell,[1] and a comparison of the results obtained by the two methods is of considerable interest. It should, however, be remembered that the list of lines given here is based upon but ten plates, and that these include only three separate spots, while Mitchell's results are derived from a much greater number. Excluding the "band-lines" in the region λ 5030–λ 5215, Mitchell's list gives a total of 352 lines between λ 5000 and λ 5850 which are affected. The table above gives a total of 345. Of these, 267 are common to both lists; 85 are given by Mitchell which do not occur in our list; and 78 are given above and are not found in Mitchell's table. The

[1] *Astrophysical Journal*, **22**, 4, 1905.

TABLE I

LINES AFFECTED ON THE PHOTOGRAPHS

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5009.83	*Ti, Co*	00	1–2				1–2	1–2						
5013.48	*Cr, Ti*	2	2–3				2–3	2–3						
5016.34	*Ti*	2	3				3	3						
5017.76	*Ni*	3	3				n. c.	n. c.						Winged
5020.21	*Ti*	2	3				3	3						
5021.78	*Fe*	0	1				1–2	0–1						Hazy
5022.11	*Cr*	000	0				0–1	0						
5023.05	*Ti*	2	2–3				2	3						
5025.03	*Ti*	3	4				4	4						
5025.75	*Ti*	1	2				2	1–2						
5027.30	*Fe*	3	4				4	4						Rowland's intensity poor
5027.94	*Fe*	1	0				0	0		0–1				
5029.66	...	0000	00–0					0		00				
5036.64	*Ti*	2	3				3	3		3				
5038.58	*Ti*	2	3–4				3–4	3–4		3				
5039.43 }	*Fe*	3	} 4				4	4		4				Winged
.54 }	*Ni*	00												
5040.14	*Ti*	3	4				3–4	4		4				
5040.79	*Ti*	00	1				0–1	1		1				
5043.76	*Ti*	00	0–1				n. c.	0–1		1				
5045.58	*Ti*	00	0–1				0–1	0		1				
5048.61	*Fe*	3	2–3				2	2		n. c.				
5052.08	*Cr*	0	0–1				0–1	0–1		0–1				
5053.06	*Ti*	0	1				1	0–1		1				
5058.67	*Fe*	00	0					0		0				
5060.26	*Fe*	3	3–4		n. c.	4	n. c.	4		4	n. c.			
5062.28	*Ti*	0	1		0–1	1	0–1	1		1	0–1			

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5064.84	*Ti*	3	4		3–4	3–4	4	4		4	4			
5066.08	*Cr*	000	1–2		1	1–2	1	2		2	2			Blend
.17	*Ti*	000												
5066.91	...	00	0		0	0	0–1	0		0				
5068.48	*Cr, Ti*	0000	0				00–0	0		0				
5071.67	*Ti*	0	1		1	1	1	1		1–2	1			
5073.11	*Cr*	1	1–2		n. c.	1–2	1–2	2		2	n. c.			
5073.92	...	000	0				0	0		00–0				
5080.71	*Ni*	4	3–4		3–4	n. c.	3	3		n. c.	3			Hazy
5082.53	*Ni*	2	1		1	1	1	0		1	0–1			
5083.88	...	000	00			0	00	00		00				
5085.34	*Ti*	0000	00				00	00						
5086.95	...	000	0		0–1	0	0–1	0		00				
5087.24	*Ti*	0	2		1–2	2	2	2		1–2	2			
5092.28	...	0000	0				0	0						Probable blend
.48	...	00												
5094.20	...	000 N	0			00–0		0						
5110.57	*Fe*	5	5–6		n. c.	6	5–6	6		6	n. c.			Hazy
5113.30	*Cr*	00	0		n. c.	0	0	0		0–1	0			
5113.62	*Ti*	0	1		1	1	1	1		1–2	1			
5115.96	*Fe*	0	00–0			00	00	0		00				
5120.59	*Ti*	0	0–1		0–1	1	1	1		n. c.	n. c.			
5120.80	...	000	00–0			0	00–0			00				
5121.73	*Ni*	0	1–2		1–2	1	1	1		1–2	2			Thinned on violet edge
.82	*Fe*	2												
5122.97	*Co*	000	0–1		0	0–1	0	1		0–1				
5123.64	*Cr*	000	00		n. c.	00	00	00		00–0	00–0			
5127.86	...	00	0		n. c.	0	0	0		1	0			
5129.80	*Fe*	1	00		00	000	00	00		0	000			

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5131.64	*Fe*	2	1–2		n. c.	1	1	n. c.		n. c.	1			
5132.84	. . .	00	000		n. c.	n. c.	000	0000		0000	000			
5136.27	*Fe*	00	1		1	1	1	1		0–1	0		0–1	
5137.25	*Ni*	3	3–4		4	3–4	4	n. c.		n. c.	4		n. c.	
5139.43	*Fe*	4	9		10	8	10	8		10	9		10	Winged
.64	*Fe*	4												Hazy to violet
5141.92	*Fe*	3	3–4		4	4	n. c.	n. c.		n. c.	n. c.		4	Hazy
5144.85	*Cr, C*	00	1				1	1					0–1	
5147.65	*Ti*	0	2		1–2	1–2	1–2	2		2	2		2	
5148.41	*Fe*	3	3–4		n. c.	3–4	n. c.	3–4		n. c.	4		4	
5152.09	*Fe*	3	4		4	4	4	4		n. c.	4		4	Fringe on violet edge
5152.36	*Ti*	0	1		0–1	1	1	1		1–2	1		1	
5156.82	*C*, —	00	1				0–1	1						
5159.23	*Fe*	2	1		1	1	1–2	1–2		1–2	1		1–2	
5164.72	*Fe?*	1	0–1		0	0–1	0–1	0–1		n. c.	0		0	Bright space at 5163.7
5166.45	*Cr, Fe*	3	3–4		3–4	3–4	3–4	4		4	4		n. c.	
5169.07	*Fe*	3	5		5	5	5	5		6	5		6	Weak on red edge
.22	*Fe*	4												
5176.95	*V*	000	0		0	0	0	0–1		0	00–0		0	
5177.41	*Fe*	0	1–2		1–2	1–2	1	1		1–2	1		1–2	Hazy
.58	*Co*	00												
5187.62	. . .	000	0		0	0	0	00–0		00	0		0	
5188.08	*Fe*	1	0–1		n. c.	0–1	0–1	0–1		n. c.	0–1		0–1	
5188.86	*Ti*	2	6		6	6	6	6		6	n. c.		6	Hazy toward violet
89.02	*Ca*	3												
5191.63	*Fe*	4	5	5–6	5	5	5	5		5	5		n. c.	Hazy
5192.16	*Cr*	00	0		0	0	00	0		0–1			0	
5195.11	*Fe*	4	5	5	5	5	5	5		n. c.	5		n. c.	Winged
5196.23	*Fe*	1	2	2	2	2	n. c.	n. c.		2	2		2	Fringe on violet edge

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5196.61	*Cr*	0	1		1	1	0–1	0–1		1–2			2	Widening due to *Mn* component probably
.74	*Mn*	00												
5197.33	*Ni, Mn*	00	0–1					0–1					0–1	
5197.74	...	2	0–1			0	0	0–1		1			1	
5198.89	*Fe*	3	4	5	4–5	4	4	4		4	4		4–5	
5200.36	*Cr*	00	00–0	0	n. c.	n. c.	n. c.	0		00–0	00–0		00–0	
5201.26	*Ti*	000	0	0	0	0–1	0	0		0	0		0	
5204.68	*Cr*	3	10	10	10	9	10			10	10		10	Fringe on violet edge
.77	*Fe*	5												
5206.22	*Cr-Ti*	5	6	7	7	6	5–6			6	6		6	
5208.60	*Cr*	5	6	5	7	6	6			6	5		6	
5210.56	*Ti*	3	5	4	5	5	5			5	5		5	Hazy
5212.86	...	000 Nd?	0							0			0	
5214.29	*Cr*	00	0		0–1	0	0			0			0	
5214.78	...	00	0		0–1	0	0			0			0	
5218.08	*Fe*	0	0–1	1	0–1	0	n. c.			n. c.	0–1		1	
5221.93	*Cr*	0	1	1	0–1	0–1	1			0–1	1		1	
5222.56	*Cr*	00	00–0	00	0	00–0	00–0			00–0	n. c.		00–0	
5222.85	*Ti, Cr*	00	0	00	0–1	0	0			0	0		0	
5223.79	...	000	0	0	0	0	00			0	0		0	
5224.24	*Cr*	000 N	00–0							00–0			00–0	
5224.47	*Ti*	0	1	1	1	1	1			1	1		1	
5225.10	*Cr*	0	1–2	1	2	1–2	1			2			1–2	
.20	*Cr, Ti, Fe*	00												
5225.70	*Fe*	2	3	3	3	3	2–3			3–4	4		3	
5227.04	*Fe-Cr*	3	4	4	4	4	4			4	3		3–4	
5230.38	*Co, Cr*	00	1	1	1	1	0–1			1	1		0–1	
5233.12	*Fe*	7	8	8	8	8	7–8			n. c.	8		8	Winged
5234.02	...	0000	00		00	00				00			0	

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5234.38	...	000	00		00	000				00			00	
5234.79	...	2	1	1	n. c.	1	0–1			1	1		1	
5235.35	*Co*	000	00–0	0	00	00	00			00	00		0	
5237.49	*Cr?*	1	0–1	0–1	0–1	0–1	0–1			0–1	0		n. c.	
5238.74	*Ti*	000 N	1	0–1	1–2	1	1			1–2	1		1–2	
5239.14	*Cr*	00	0	0	0	0	0			0–1	0		0–1	
5241.04	...	000	00	00–0	00	00–0	00–0			00	00		n. c.	
5243.53	*Cr*	00	0	0	0	0	0			0			0	
5246.73	...	0000	00–0	0	0	00	00			00–0			00–0	
5247.23	*Fe*	2	1–2	1–2	1–2	n. c.	1–2			n. c.	2		2	
5247.74	*Cr*	2	2–3	2–3	2–3	n. c.	2–3			3	2–3		3	
5249.28	*Fe*	00	0	n. c.	0	0	0			0	0		0	
5250.38	*Fe*	2	3	3	3	2–3	2–3			3	3		3	
5251.67	...	...	00–0	00	0	00	00–0			00			0	Rowland gives no line here
5252.15 }	*Fe*	0	2	2	2	1–2	2			2	2		3	
.28 }	*Ti*	000												
5253.20	...	00	0	0	0	00–0	00			0–1	0		0	
5255.12	*Fe*	3	4	4	5	4	4			4–5	4		4	
5255.49	*Mn*	0	0–1	0–1	0–1	n. c.	0–1			n. c.	0–1		0–1	
5255.91 }	...	000	1	1	1–2	1	1–2			0–1	1		1	
.97 }	*Ti*	0000												
5260.14	...	000	0	0	0	0–1	00–0			00				
5260.56	*Ca*	0	1	1	1	1	1			1–2	1		1–2	
5264.33 }	*Cr*	4	9	8	9	8	9			10	9		9	
.42 }	*Ca*	3												
5264.98	...	0	00	00–0	n. c.	00–0	000			00	00		00	
5266.14	*Ti*	0	0–1	n. c.	1	0–1	0–1			0–1	n. c.		0–1	
5269.72	*Fe*	8 d?	9	10	8	9	10			10	8		9	Winged
5275.15	...	0	00	n. c.	00	00	000			00	00		n. c.	

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5275.34 }	*Cr*	00	} 2–3	2	2–3	2–3	2			2	2–3		2–3	
.45 }	...	1												
5275.93	*Cr*	1	2	1–2	2	2	2			2	1–2		2–3	Hazy
5280.54	*Fe*	1	1–2	1–2	1–2	1–2	n. c.			1–2	n. c.		1–2	
5282.58	*Ti*	00	1	0–1	1	1	1			1	1		1	
5284.60	*Fe, Ti*	00	0		0	0	0			00–0			00–0	
5284.79	...	00	00–0		00					00–0			0	
5285.82	...	000	00		0	00–0	00			00			00	
5287.35	*Cr*	000	0	0	0–1	0–1	0			0				
5289.45	...	000	00–0	00	0	0	00			00–0				
5290.98	...	000	00			0	00			00				
5295.96	Awv?	00	1	0–1		1–2	1			1	1		0–1	
5296.87	*Cr*	3	4	4		4–5	4–5			4	3–4		4	
5297.41	*Cr, Ti*	000	00–0	00		0	00			00–0	00		0	
5298.46	*Cr*	4	6	5–6		6	6			6	5		6	Hazy
5300.15	...	00	0–1	0		1	0–1			0	0		1	
5300.93	*Cr*	2	3	3		3	3			3	3		3	
5301.22	*Co*	00	00–0	n. c.		0	0			n. c.	00–0		0	
5302.48	*Fe*	5	5–6	6		6	6			n. c.	6		n. c.	
5304.36	*Cr*	0	1	1		1	0–1			0–1			1	
5307.54	*Fe*	3	4	3–4		4	4			4	3–4		4	
5313.03	*Cr*	0	0–1	1		0–1	n. c.			n. c.	0–1		0–1	
5324.37	*Fe*	7	7	n. c.		n. c.	8			n. c.	n. c.		n. c.	Winged
5329.33	*Cr*	3	4	3–4		4	3–4		4	3–4	4		4	
5329.98	*Cr*	0	0–1	n. c.		n. c.	0–1		0–1	n. c.	0–1		0–1	
5331.64	*Co*	00d	0	0–1		0	00–0		0	0	0	0	1	
5335.05	*Co*	1	0	0		0–1	0		0	0	00	0–1	0	
5337.91	...	0	00						000	00		00		
5338.52	...	00 N	0–1	0		0–1	1		0	0		0	0–1	

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5341.21	*Fe*	7	10	10		10	10		10	10		10	10	Weak on red edge
.34	*Mn*	1												
5343.15	...	0000	00	00		00				00		000		
5344.94	*Cr*	00	00–0	0		00–0			0	0		n. c.		
5345.99	*Cr*	5	7	6		7			6	7	7		7	Winged
5348.51	*Cr*	4	6	6		7			6	6	6	6	6	Winged
5349.65	*Ca*	4	4–5	n. c.		5			n. c.	n. c.	5	5	n. c.	
5351.26	*Ti*	00	1	1		0–1			0	1	1	1	1	
5356.27	...	000	00	00–0		00			00	00–0		000–00	00	
5366.83	...	000	0	0		0			00–0	0	0	0–1	1	
5369.78	*Co-Ti*	1	2	2–3		2–3	2		2	1–2	2	2	3	
5371.66	*Cr?*	4	10	10		10	n. c.		10	10	10	10	10	Winged
.73	*Fe*	3												
5373.90	*Fe, Cr*	2	2–3	n. c.		2–3	n. c.		2–3	2–3	2–3	n. c.	2–3	
5384.83	...	000	00–0	00		00	00–0			00		00–0	00–0	
5387.16	*Fe, Cr*	0	1	0–1		1	1		1	0–1	1	1	1	
5387.77	*Cr*	00	1	0–1		1	1		0–1	0	0	1–2	1	
5389.37	...	000	0–1	0		0	0–1		0	0	0	1	1–2	
5390.05	...	00	0	0		0	0		n. c.	0	0	1	0–1	
5393.38	*Fe*	5	5–6	n. c.		5–6	6		n. c.	6	6	n. c.	n. c.	
5394.84	*Mn*	1	4	3		4	4		4	4	3	4	4	Diffuse
.91	*Mn*	1												
5396.78	*Ni*	000 N	1	1		1	0		0	1	0–1	1–2	1–2	
5397.34	*Fe*	7 d?	9	8		9	8		8	10	8	10	9	Winged
5399.68	*Mn*	1 Nd?	1–2	2		1–2	1–2		1–2	1–2	2	1–2	1–2	Hazy
5401.47	...	0	1	0–1		0–1	1		1	1	1	1	1	
5404.36	*Fe*	5	5–6	n. c.		n. c.	6		6	n. c.	6	n. c.	6	
5405.55	...	1	1–2	2		1–2	1–2		n. c.	1–2		1–2	n. c.	
5405.99	*Fe*	6	8	8		8	8		7	8	7	8	8	Winged

TABLE I—*Continued*

Rowland: Wave-Length	Rowland: Element	Rowland: Solar Intensity	Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
5407.59	*Mn*	0	2–3	2		2–3	2–3		2	2–3	2	2–3	2–3	Diffuse
.69	*Mn*	0												
5409.02	...	000	0	0			0		00	00	00–0	1	1	
5410.00	*Cr*	4	6	5		6	6		n. c.	6	5–6	7	7	Fringe on violet edge due to *Ti* line
5413.00	*Mn*	00	00–0	0		n. c.	n. c.		00–0	00–0	0	0	00–0	
5413.89	*Mn*	00 N	0	0		00–0	00–0		n. c.	0	0	0–1	0	
5419.42	A ?	0000	00	000		00–0	00–0					0	00	
5420.51	*Mn*	0 N	3	2–3		2	3		3	3	2–3	3	3	Rowland's intensities poor
.61	*Mn*	0 N												
5425.46	...	1	0–1	0–1		0–1	n. c.		0–1	0	0–1	n. c.	n. c.	
5426.47	...	00	2	2		2	2–3		1–2	1–2	2	2	2	
5429.35	...	00	00–0	0		n. c.	00–0		00–0	0	00–0	0	00–0	
5429.91	*Fe*	6	8	7		8	7		8	8	7–8	8	n. c.	Hazy
5432.75	*Mn*	1	3	2–3		2–3	3		2–3	2–3	3	3	3	
5436.80	*Fe*	1	2	2		2	1–2		1–2	2	1–2	2	2	
5438.51	...	000	0	00–0		00	0		0	0	0	0–1	00–0	
5440.86	...	000	00–0	00		00	00–0			00		0	00–0	
5442.63	*Cr*	00	0	0		0	0		0	n. c.	0	1	0	
5447.13	*Fe*	6	8	8		8	8		8	7	8	8	n. c.	Winged
5448.58	...	00	00–0	0		0	00		00–0	00–0		00–0	n. c.	
5453.86	...	000	00–0	00		00	00–0		0	0	00	0–1	0	
5457.64	*Mn*	000	0	0		0	00–0		0	00–0	0	0	00	Hazy
.70	*Mn*	000												
5460.72	...	00	2–3	2		2–3	2–3		2	2	2	3	3	
5461.76	...	0	1	1		1–2	1		1	0–1	0–1	1	0–1	
5464.18	*Cr*	000	00	00		0	00		00	00	00	00	00–0	
5465.94	...	...	0									0	00–0	Rowland gives no line here
5470.80	*Mn*	0	2–3	2		2	2–3	2–3	3	3	2	3	3	Hazy
.88	*Mn*	0												

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5471.41	*Ti*	000	1–2	1		1–2	1–2	1–2	1–2	1–2	1	1–2	1–2	
5473.37	...	00	00–0	00–0		0	00–0	0	n. c.	0	0	00–1	n. c.	
5474.44	*Ti?*	00	0	0		0	0	0	0	0	0	1	0–1	
5474.96	...	0000 N	00–0					0			00–0	00–0	00–0	
5477.90	*Ti*	00	1–2	1		1–2	1–2	1–2	1	1	1	2	1–2	
5482.08	...	00	1–2	1		1–2	1–2	1–2	1	1	1	2	1	
5482.47	...	000 N	00–0									00	0	
5483.57	*Co*	1 d?	1–2	1–2		1–2	1–2	1–2	1–2	1–2		1–2	n. c.	
5484.85	...	000	00–0	00		00	00–0	0		00–0	0	0	00–0	
5485.76	...	000	0									00–0	0	
5488.37	...	00 Nd?	1	0–1		1	0–1	1	1	1	1	1	1	
5490.37	*Ti*	0	3	3		2	3	3	3	3	3	3	3	
5490.90 } 91.04 }	... ...	0 000	1–2	1		1–2	1–2	1–2	0–1	1	1	1–2	2	Widening due to red component mainly
5493.71	*Fe*	1	1–2	n. c.		1–2	1–2	1–2	1–2	1–2	1–2	1–2	1–2	
5494.68	*Fe*	0	0–1	n. c.			0–1	0–1	0–1	1	1	0–1	0–1	
5495.10	*Ni*	00	0	0			00–0	00–0	0	00–0	0	0	0	
5495.66	...	...	00–0					0	00			00–0	00	Rowland gives no line here
5496.12	...	0000	00									00	00	
5497.74	*Fe*	5	6	6		n. c.	n. c.	n. c.	7	8	6	n. c.	7	
5504.12	*Ti*	0	1	1		1	1	1	1	1	1–2	1	1	
5506.10	*Mn*	1	2	1–2		1–2	1–2	2	2	2	2	1–2	2	
5507.00	*Fe*	5	7	6		6	6	7	7	7	6–7	7	7	Winged
5512.01	...	00	0	0		0	0	0	0	00–0	0	1	0	
5512.74	*Ti*	2	3	3		3	3	3	3	3	3	3	3	
5514.56	*Ti*	2	3	2–3		3	2–3	3	3	3	2–3	3	3	
5514.75	*Ti*	2	2–3	2–3		3	2–3	2–3	2–3	2–3	2–3	3–4	2–3	
5516.95 } 17.03 }	*Mn* *Mn*	0 0	2	1–2		1–2	1–2	1–2	2	2	2	2–3	2	Diffuse

TABLE I—*Continued*

Rowland: Wave-Length	Rowland: Element	Rowland: Solar Intensity	Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
5520.73	...	ooN	1	1		0–1	1	1	0	0		1	2	
5527.80	...	ood	00–0									00–0	0	
5529.38	*Fe*	00	0									0	0	
5531.00	*Ti*	ooN	0–1	1		0	0–1	1	0–1	1	0	0–1	0–1	
5535.06	*Fe*	2	1						1–2	1		1	1	
5535.64 }	*Fe*	2	} 3–4	3–4			4	3–4	3	3		4	4	
.78 }	...	0												
5537.93 }	*Mn*	00	} 2	2	2	1–2	1–2	1	1–2	2	2	2	2	Diffuse
38.02 }	*Mn*	00												
5538.74	*Fe*	1	1–2	1–2	n. c.	1	1–2	1–2	1–2	2	1	2	1–2	Rowland's intensity poor
5546.73	*Fe*	2	2–3	2–3	2–3	2–3	2–3	2–3	2–3	2–?	n. c.	n. c.	n. c.	
5547.22	*Fe, V*	1	1–2	2	2	1–2	2	2	1–2	1–2	1–2	1–2	1–2	
5555.86 }	...	000	} 00–0		00			0	0	00		00	00–0	
.95 }	...	0000												
5565.70	*Ti*	00	2	2	2	1–2	1–2	2	1–2	1–2	1–2	2	2	
5573.76	...	0000	00	00	00	00	00	00	00			00	00–0	
5579.57	...	000	00–0		0	0	00	00	00	0		00	00–0	
5582.20	*Ca*	4	5	5	5	4–5	5	n. c.	n. c.	n. c.	n. c.	6	5	Winged
5583.19	...	000	00		00–0	00		00				00	00–0	
5584.73	...	000	00	00–0	0	00	n. c.	00	00	00–0	n. c.	00	00	
5586.99	*Fe*	7	8	8	8	8	8	8	9	9	8	8	8	Winged
5588.99	*Ca*	6	7–8	7	7	7–8	8	8	7	7	7	8	8	
5590.34	*Ca*	3	3–4	4	4	4	4	4	n. c.	n. c.	n. c.	n. c.	4	
5590.93 }	*Ti*	000	} 00–0		0	00–0	00–0	00	00–0	0		n. c.	00	
.91.04 }	*Ti*	000												
5594.69	*Ca*	4	5	5–6	4–5	5	n. c.	5	5	5	5	5	5	Winged
5598.71	*Ca*	4	5	5	5	5	5	5	5	6	5	6	5	Hazy
5605.17	...	000	0	0	0	0	00	0	0	00–0		1	0	
5619.82	...	0	0–1	0–1	0–1	0–1	0–1	0–1	0–1	n. c.		n. c.	0–1	
5625.10	...	000	0	0	0	00	00	0–1		0		0	0–1	

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5626.26	...	...	1	1	1	0–1	1	1–2		0		1	1	Rowland gives no line here
5627.86	*V*	00	2–3	2	3	1–2	2–3	2–3		2–3	2–3	3	3	
5628.87	*Cr*	00	0–1	0–1	0–1	0	1	0–1		0–1		1	1	
5630.31	...	000	00–0									00–0	0	
5644.26 }	...	00	} 2–3	2	2–3	2	2	3		2	2	3	3	
.37 }	*Ti*	0												
5645.83	*Si*	1	00–0	0	0	00	0	0			0	000	00	
5646.04	...	00	1	1	1	0–1	1	1–2		0–1	1	1–2	1–2	
5647.46	*Ti*	00	0–1	0–1	1	0	0	0		0–1	0–1	0	0–1	
5648.80	*Ti*	00	2	2	2	1–2	1–2	2	1–2	1–2	1–2	2	2	
5651.69	*Fe*	0	0–1	0–1	1	n. c.	0–1	n. c.	n. c.	0–1	1	n. c.	1	
5654.09	*Fe*	1	1–2	1–2	n. c.	n. c.	n. c.	n. c.	1–2	1–2	1–2	1–2	1–2	
5657.67	...	000	1	1	1	1	1	1–2	0–1	0–1	1	1–2	1–2	
5658.10	*Y*, —	2	1–2	n. c.	1–2	1–2	n. c.	n. c.	n. c.	1–2	1–2	1–2.	1–2	
5662.37	*Ti*	0	1–2	1–2	1–2	1–2	1–2	1–2	1–2	1–2	1–2	2	2	
5663.16	*Ti, Fe, Y*	1	1–2	1–2	2	2	1–2	1–2	1–2	1–2	1–2	1–2	2	
5664.80	...	000	0			0	00	0		0		0	0	
5665.78	*Si*	1N	0					0				00–0	0	
5668.59	*V*	000	1	1	1–2	0–1	0–1	1–2	0–1	0–1	1–2	1	2	
5669.26	...	1	0	0	0	0	0	0	0–1	0–1	0	0	0	
5671.07	*V*	0	3	3	3	2–3	2–3	2–3	2–3	3	3	3–4	3–4	
5672.05	*Sc*	0	2	2	2	2	2	2	1–2	2	2	2–3	2	
5675.65	*Ti*	2N	2–3	3	2–3	n. c.	2–3	3	3	2–3	2–3	2–3	3	
5680.15	...	000	0–1	0	0	0	0–1	1	00–0	0	1	0	0–1	
5682.87	*Na*	5	7	7	7	7	7	7	6	6	6	8	6	
5684.71	*Si*	3	1–2	2	2	2	2	1–2	1–2	1–2	2	0	1	
5687.06	...	000	1–2	1–2	1–2	1	1–2	2	1	1	2	2	1–2	
5688.44	*Na*	6	7	7	8	n. c.	8	6	n. c.	n. c.	7	8	7	Winged
5689.69 }	*Ti*	0	} 2	2	2	1–2	2	2	2	2	2	2	2–3	
.81 }	A?	0												

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 40	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5690.65	*Si*	3	2–3	2	2–3	2	n. c.	n. c.	n. c.	2	2	2	n. c.	
5694.96	*Cr*	0	1	1	0–1	1	0–1	n. c.	0–1	1	1	1	0–1	
5698.56	*Fe, Cr*	1	2	2	2	2	1–2	2	2	1–2	2	1–2	2	
5698.75	*V*	1	3–4	4	4	3	3	3	3	3	3–4	3–4	3	
5700.51	*Cu?*	00	2–3	2–3	3	2–3	2	2–3	2–3	2	2	2–3	3	
5701.32	*Si*	0N	00	00	00	00–0	00	00	00	00	000	00	00	
5702.54	*Cr*	0	1	1–2	1–2	0–1	1	0–1	1	1	2	1	1	
5702.88	*Ti*	000	0–1	1	1	0	1	0–1	0	0–1	1	0–1	1	
5703.80	*V*	1	3	3	3	3	2–3	3	2–3	3	3	3	3–4	
5707.20	*V*	0	3	3	3	3	3	3	3	3	3	3	3–4	
.26	*Fe*	1												
5708.62	*Si*	3	1–2	2	2	2	1–2	2	2	2	1	1	1	
5709.60	*Fe*	5	7	6	7	7	7	7	8	8	6	7	7	
5712.10	*Fe*	3	5	4	5	5	5	5	4	4	6	6	5	Hazy
5713.00	*Cr*	0	1–2	1	1–2	1	1–2	1–2	1–2	2	2	1	1–2	
5714.12	...	000	00–0	0	00	00	00	0	0	0	0	0	0	
5716.67	*Ti*	00	2	1–2	2	2	2	2	1	1	2	2	2	
5717.92	...	000	00		00			00	00		00–0	00	00	
5720.67	*Ti*, A	0	1–2	1	1–2	1	1–2	2	1	1	1	1	2	
5727.27	*Ti-V*	2	3–4	3	3–4	3–4	3	3	3–4	3	3–4	4	4	
5727.87	*Cr?*	00	3	3	3	3–4	3	3	3	3	3–4	3–4	4	
5731.44	...	00	4	4	4	4	4	4	3	2–3	4	4	4	
5735.79	A	0	1	0–1	0–1			1–2	1	1		1	1–2	
.92	...	00												
5737.29	...	0	3–4	4	4	3	3–4	3	3	3	3	4	4	
5739.70	...	0	2	1–2	1–2	2	1–2	1–2	2	1–2	2	2–3	2	
5740.20	...	0	1–2	1	2	0–1	1–2	1	1–2	1	2	1–2	1–2	
5741.43	A ?	000	00–0	0		00		00		0		00		
5743.64	...	00	3	3	3	3	3	3	2–3	2	4	4	3	
5744.15	...	00	0–1	1						0	0–1	0–1	0	

TABLE I—*Continued*

Rowland			Mean Spot Intensity	L 17	L 18	L 19	L 20	L 21	L 24	L 27	L 29	L 41	L 43	Remarks
Wave-Length	Element	Solar Intensity												
5748.18	*Fe*	2	2–3	2–3	2–3	n. c.	n. c.	2–3	2–3	2–3	n. c.	2–3	n. c.	
5748.58	*Ni*	2	2–3	3	2–3	2–3	2–3	2–3	2–3	2–3	n. c.	3	2–3	
5754.88	*Ni*	5	5–6	5–6	n. c.	n. c.	6	5–6	n. c.	6	n. c.	7	6	Hazy
5760.57	*Fe*	1	1–2	2	1–2	1–2	1–2	1–2	1–2	1–2	2	1–2	1–2	
5762.48 }	*Ti*	oooNd?	} 2–3	2	2	3	2–3	3	2–3	2	2	2–3	2	Widening due mainly to *Ti* line
.64 }	*Fe*	1												
5766.55	*Ti*	0	1–2	2	2	2	1–2	1–2	1–2	1–2	2	2	1–2	
5771.82	. . .	00	0	n. c.	0	0	0	0–1	0	0	0	0		
5772.36	*Si*	3	1–2				1–2	2	2	2		0–1	1–2	
5774.25	*Ti*, A	0	1–2	2	1–2	1–2	1–2	1	1	1	2	1–2	1–2	
5776.96	A, —	000	0–1		0	0	0	0			1	1	0–1	
5778.68	*Fe*	1	2	2	2	1–2	1–2	2	2	2	2	2	1–2	
5780.82	*Fe*	2	2–3	3	2–3	3	2–3	n. c.	3	n. c.		n. c.	n. c.	
5781.02 }	*Fe*	0	} 1	1	1	1	1	1	1	1	1	1	1	
.13 }	*Cr*, *Ti*	00												
5781.40	*Cr*	0	2	2–3	2	2	1–2	1–2	1–2	1–2	3	1–2	2	
5781.97	*Cr*	0	1	1	1	1	1	1	1	1	2	0–1	1	
5783.29	*Cr*	2	3–4	4	4	4	3–4	3–4	3	3	4	3	3	Hazy
5784.08	*Cr*	3	4	5	4	5	n. c.	n. c.	3–4	4	4	4	3–4	
5785.19	*Cr*	2	2–3	3	3	3	2–3	n. c.	n. c.	n. c.	3	3	3	
5785.95	*Cr*	1	2–3	3	2–3	3–4	3	2–3	2	2	2	2	3	
5786.19	*Ti*, *Cr*	0N	1–2	2	1–2	2	1–2	2	1	1	2	1–2	1	
5787.24	*Cr*	00	0	0	0	0	0–1	0	0–1	0		0	1	
5798.08	. . .	3	2–3	2	2	2	2–3	n. c.	2	2	2–3	2–3		
5804.48	*Ti*	0	1–2	1–2	1	0–1	1–2	1–2	1–2	1–2	1–2	1–2	1–2	
5805.99	*La*	0	0–1	n. c.	0–1	0–1	n. c.	0–1	0–1	0–1	1	n. c.		
5823.91	. . .	00	1–2	2	1–2	2	2	1–2		1	1	2		
5828.10	. . .	0	1	1	1	1	1–2	1	1	1	1			
5847.22	*Ni*	1	2	2	2	3	3	2–3	1–2	1–2	3			
5853.54	. . .	000	0	00	0	0			1	0	0			

character of these missing lines is very different in the two cases. Those absent from our list are for the greater part lines of medium or considerable intensity which appear in Mitchell's list as only slightly affected. In the case of such lines it is always difficult to be certain of a slight variation in intensity, and, while most of these lines have been observed by us, the mean variation has been too small for them to be included in the table. On the other hand, the lines present in our list and not in that of Mitchell are for the most part coincident with very faint lines in the solar spectrum, and would be classed as "band-lines" if we made use of that term.

Although the list of lines which we have given is intended rather to show the possibilities of the photographic method than to serve as a definitive table, it will not be out of place to give a brief analysis of them with especial reference to the elements to which they belong. An inspection of the table gives the following results:

TABLE II

Element	No. of Lines Affected	Mean Change of Intensity	No. of Lines Weakened
Fe..................	60	0.5	10
Ti..................	48	1.2	..
Cr..................	43	0.9	1
Mn..................	13	1.1	..
Ni..................	9	0.3	2
Ca..................	7	0.9	..
Si..................	7	—1.1	7
Co..................	6	0.3	1

Lines assigned to two or more elements	25
Blends	20
Unknown	94
Water vapor (all marked " ?") by Rowland	3
Sodium	2
Sc, *La*, *Cu*, each	1

In forming the third column of the table, which gives the mean change of intensity on Rowland's scale, care has been used in combining results for lines above 1 and below 1 in intensity, the values of the intervals being by no means the same in the two cases. For example, the change in intensity between 1 and 2 is not at all the same as between 00 and 0. A considerable number of observations

was made in order to eliminate difficulty from this cause, and the results cannot be much in error so far as this source is concerned.

These observations strongly confirm Mitchell's conclusion that lines due to water-vapor are not affected in the spot spectrum. But three lines in the list are assigned by Rowland to water-vapor alone, and in the case of each of these the identification is marked doubtful.

The fact that only a little more than one-fourth of the lines in the table are "unknown" is decidedly opposed to Lockyer's view that at the period of sun-spot maximum the lines due to known elements are replaced by unknown lines. Even of this fourth a considerable proportion consists of such faint lines that their identification by Rowland would be improbable, since in the case of lines of intensity 00 on his scale an identification is much more the exception than the rule, and since the probability grows less with decreasing intensity. The evidence afforded by the iron lines is also opposed to Lockyer's conclusion. More than one-sixth of the total number of lines affected is due to that element alone, and it also enters largely into the composite and blended lines. It seems to us probable, as Cortie has suggested, that changes in the behavior of the iron lines may depend upon the character of the spots in which they occur, but at present we have by no means sufficient evidence to speak definitely on this point.

In a recent paper,[1] discussing his observations of the sun-spot spectrum in the region C to D, Fowler draws the conclusion that in the case of elements which are represented in the Sun by comparatively faint lines, such as titanium, vanadium, and chromium, the lines in the spot are strengthened in proportion to their intensities in the Sun. Our results do not support this conclusion. In the case of titanium, which is the element Fowler discusses in detail, we have, for example, in the lines λ 5566, λ 5649, and λ 5717 instances of lines strengthened from 00 to 2 on Rowland's scale. On the other hand, the stronger lines λ 5023, λ 5515, and λ 5676 are only very slightly affected, rising from 2 to 2–3 on the same scale. Perhaps an even more striking case is that of the line λ 5490, which rises from a solar intensity of 0 to 3 in the spot. This is a value that is surpassed

[1] *Monthly Notices*, **65**, 205–218, 1905.

by very few lines with a solar intensity as great as 2. Fowler remarks that "in photographs, at least, a general strengthening of all the lines belonging to an element produces a more obvious effect on the weaker lines than on the strong ones, though all may be intensified in the same ratio." This may have some effect in the case of elements with such strong lines that it is difficult to find lines in the adjoining solar spectrum of sufficient intensity for comparison purposes. In the case of titanium, however, even the strongest lines in the region under discussion are of very moderate intensity, and plenty of suitable comparison lines are available, so that it is difficult to see how much error can arise from the source which Fowler mentions.

In concluding this preliminary discussion of our results, attention should be called to the remarkable behavior of silicon, all the lines of which in this region of the spectrum, 7 in number, are much weakened. Mitchell finds a similar result for 5 lines. In view of the importance attaching to the carbon group of elements in the Sun, this result is of especial interest.

"BANDS" IN THE SPECTRA OF SUN-SPOTS

In describing the spectrum of a spot observed from April 11 to April 13, 1869, Secchi speaks of several groups of very fine lines which lie close together in the general spectrum of the Sun, but appear in spots as diffuse and nebulous lines:

> Dans la région du vert, il y en a un très-grand nombre qui deviennent très-noires dans les taches, tandis que sur le reste du disque on a beaucoup de peine à les distinguer. Ces systèmes ne paraissent cependant pas être des créations nouvelles tout à fait particulières aux taches; ils correspondent ordinairement à des raies très faibles indiquées par Kirchhoff; mais ces raies prennent dans les taches un développement extraordinaire, ce que constitue un phénomène bien tranché et complétement caractéristique.[1]

These observations, which describe very accurately the phenomena of spot bands, have received little or no mention in the literature of the subject.

In his Mount Sherman observations, Professor Young noticed between C and D in the spot spectrum some peculiar shadings terminated sharply by hard dark lines on the less refrangible side and fading out gradually in the other direction.[2] The Greenwich obser-

[1] *Le Soleil*, 2d ed., 1, 288.

[2] *Nature*, 7, December 12, 1872.

vations of spot "bands," which have been frequently cited, were made during the years 1880 to 1883. Many of the "bands" were only about one tenth-meter broad. On November 18, 1881, the "bands" "seemed to be composed of fine lines, but this could not be ascertained with certainty."[1] Father Cortie distinguishes three types of "bands." The first, "a certain fuzzy appearance surrounding the widened portions of the dark lines," is merely a special case of widening. The second results from increased general absorption in certain parts of the spectrum, while the third is "the appearance of real bands in the selective absorption due to a spot."[2] The lack of uniformity of the general absorption is precisely what gives rise, in our photographic observations, to the appearance of bands, and particularly to the "bands" observed at Greenwich. These are included by Father Cortie in his third class (bands proper), together with the bands observed by Professor Young at Mount Sherman. Father Cortie discusses in this paper his observations of two "bands" in the red, and remarks that "these bands or groups of lines were due to the spot alone, for no trace of them could be detected when the spot was removed from the slit, and they stand out most clearly and distinctly in the darkest part of the umbra." He concludes that bands of the third class "belong exclusively to sun-spot spectra" and are "altogether distinct from the ordinary widened or darkened or obliterated lines of such spectra." Vogel's observations of spot spectra, which may be found in the *Bothkamper Beobachtungen*,[3] include a number of bands, some of which were resolved into lines. More recent observations include those made photographically at the Yerkes Observatory in 1902,[4] and the visual results of Fowler and Mitchell, which are referred to below.

Before citing these, reference should be made to Young's well-known resolution of the dark background of the spot spectrum into fine lines:

> But the most striking result is that in certain regions the spectrum of the spot-nucleus, instead of appearing as a mere continuous shade, crossed here and there by markings dark and light, is resolved into a countless number of lines, exceedingly fine and closely packed, interrupted frequently between E and F

[1] *Greenwich Photographic and Spectroscopic Results*, 1881.

[2] *Monthly Notices*, **47**, 19, 1888.

[3] Unfortunately not yet in the library of the Solar Observatory.

[4] George E. Hale, "Solar Research at the Yerkes Observatory," *Astrophysical Journal*, **16**, 216, 1902.

(and occasionally below E) by lines as bright as the spectrum outside the spot. . . . . When seeing is at the best, and everything favorable, close attention enables one to trace nearly all these lines out beyond the spot and its penumbra. But they are so exceedingly faint on the Sun's general surface that usually they cannot be detected outside the spot spectrum. . . . . Of course the resolution of the spot spectrum into lines tends to indicate that the absorption which darkens the center of the sun-spot is produced, not by granules of solid or liquid matter, but by matter in gaseous form.[1]

Dunér, in his memoir, *Recherches sur la Rotation du Soleil* (p. 12), describes his confirmation of Young's observations in the following words:

J'ai en effet vu le spectre des taches perdant tout-à-fait l'apparence d'une bande unie plus sombre que le reste du spectre solaire, laquelle il présente dans un spectroscope d'une dispersion moyenne, et montrant de très nombreuses raies sombres, projetées sur un fond du même éclat que le spectre général du disque solaire. Ces raies ne sont pas cependant uniformément réparties et à la même distance l'une de l'autre comme les lattes d'une grille. Au contraire, on voit avec une pleine sureté, surtout en portant son attention sur les espaces qui dans le spectre solaire sont vides de toutes raies tant soit peu fortes—je cite comme exemples les lacunes 5352 . . . . 5361 et 5287,5 . . . . 5292—qu'elles sont agroupées en doublets, triplets, etc., séparées par des interstices plus larges que ceux qui séparent les raies constituantes de ces groupes. Tous les interstices, autant que j'ai pu les voir, m'ont semblé être du même éclat que ceux qui se trouvent entre les groupes des raies dans le spectre solaire. En examinant très attentivement le spectre solaire, dans le prolongement d'un tel groupe dans le spectre des taches, il m'est quelquefois arrivé de découvrir un trait nébuleux excessivement faible. En un mot: tout ce que j'ai vu, me semble prouver qu'il n'y a pas de différence fondamentale entre le spectre solaire général et celui des taches. Il est au contraire fort probable, que celui-ci se forme, pour ainsi dire, par l'exagération des caractères essentiels de celui-là, les raies excessivement faibles, presque imperceptibles, devenant parfaitement visibles, et les raies qui, dans le spectre solaire ordinaire, sont fortes devenant élargies et renforcées.

In his recent paper, "Researches in the Sun-Spot Spectrum, Region F to *a*,"[2] Walter M. Mitchell, in speaking of the resolution of the spot spectrum into fine lines, remarks:

The lines are most closely crowded in the region $\lambda\lambda$ 5000–5160; in the lower

[1] A new line at λ 3884 ± 2, mentioned in this paper as exceedingly bright in the spectrum of a specially vigorous eruption of prominences, is very likely identical with the bright line at λ 3884.28 and λ 3884.67, in the "intermediate" and "abnormal" spectra described in our account of a remarkable disturbance of the reversing layer (*Astrophysical Journal*, **16**, 220, 1902).

[2] *Astrophysical Journal*, **22**, 4, 1905.

portions of the spectrum, particularly below D, the lines form groups rather than a uniform succession of lines as above the *b*'s. The writer doubts whether the greater part of these "band-lines" are lines ordinarily exceedingly faint in the photospheric spectrum, and brought into prominence by the vapors of the spot, but is inclined to the opinion that they are lines not present in the photospheric spectrum at all. . . . . Of course there are numerous "band-lines" that are fine and sharp, extending into and sometimes beyond the spectrum of the penumbra (long lines). These exceptional lines are undoubtedly faint lines in the ordinary spectrum.

Fowler observed two of the bands in the red described by Cortie (λ 6381.6 and λ 6389.0), and found them sharper on the red side, and not resolved into lines.[1] In the same region, however, Mitchell records seventeen groups of fine lines. Many of the bands observed by Maunder in the green were seen by Fowler, whose measures of their positions agree well with the positions determined by measurement of the photographs taken at the Yerkes Observatory. In his observations of the great sun-spot of February and March 1905, Fowler was able to observe the resolution of the continuous absorption band into lines, in spite of the comparatively small dispersion of his spectroscope.

The general appearance of the band was very similar to that of a complex banded spectrum, such as that of sulphur, in which the maxima or "heads" are not very pronounced. Under favorable conditions, Young and Dunér were able to trace the dark components of the spot band structure in the spectrum of the disk outside the spot, but this was not clearly seen in my observations.[2]

Fowler noticed, however, that the bright gaps which occur here and there among the crowded dark lines of the "spot bands," occupy spaces between nebulous lines of low intensity in Rowland's table.

It is accordingly not improbable that the absorbing vapor which is chiefly responsible for the darkness of a spot is thinly distributed over the general surface of the Sun, and may account for some of the very numerous faint lines of the Fraunhofer spectrum.[3]

As will be seen from the photographs reproduced in Plates IV and V, and also from the wave-lengths of the lines in the "spot-bands" given in Table III, our results completely bear out this inference. In discussing these results, the first question that arises is whether

[1] *Monthly Notices*, 65, 217, 1905.

[2] *Ibid.*, p. 515.

[3] *Ibid.*, p. 516.

the lines in our photographs are to be regarded as identical with the fine lines observed visually by Young and Dunér. These lines were frequently seen visually by Mr. Hale in his observations of spot spectra at the Kenwood Observatory with a spectroscope not differing greatly in resolving power from the instruments employed by Young and Dunér, and subsequently by us both at the Yerkes Observatory. It may be said at once that our photographs do not show as complete a resolution of the fine lines as can be observed visually. Nevertheless, we have no doubt that the majority of the lines are shown photographically, and that the lack of more complete resolution simply arises from the fact that the linear dispersion is not great enough for the purpose. The numerous lines particularly noted by Dunér, in the above quotation from his paper, as lying in the blank regions of the solar spectrum at λ 5352–λ 5361 and λ 5287.5–λ 5292, are clearly shown in our negatives, though they may not appear in the reproductions accompanying this paper (Fig. 2, Plate IV). The best evidence, however, that the lines we have recorded represent the resolution of the "spot-bands," lies in the fact that the wave-lengths of these lines agree very closely with the wave-lengths of the very faint lines in Rowland's table. In spite of the observations of Young and Dunér, the question of the identification of the fine lines in spots with the faint lines in Rowland's table has remained unsettled, as is indicated by the fact that Mitchell expresses the opinion, in a quotation given above, that the spot lines are distinct from the faint solar lines. We have here a demonstration of one of the advantages of photography, which permits accurate measurements of the wave-lengths of such lines to be made, whereas these measurements would hardly be possible in the case of visual observations.

In spite of our identification of these fine lines of the "spot-bands" with the faint lines of the solar spectrum, we cannot subscribe to the opinion expressed by Dunér "that there is no fundamental difference between the general solar spectrum and that of the spots." If, in accordance with what appears to be his view (see the above quotation from his memoir), the spot spectrum is produced by a general increase in the intensity of the lines of the solar spectrum, no such differences in the relative intensities of the spot lines as are plainly shown in

PLATE IV

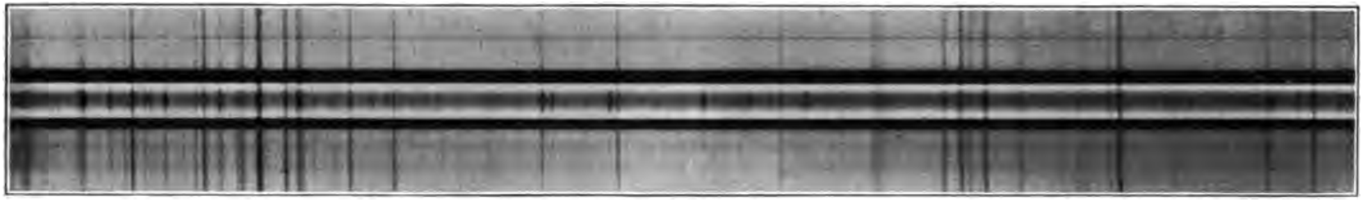


FIG. 1.—Region $\lambda 5695$–$\lambda 5775$

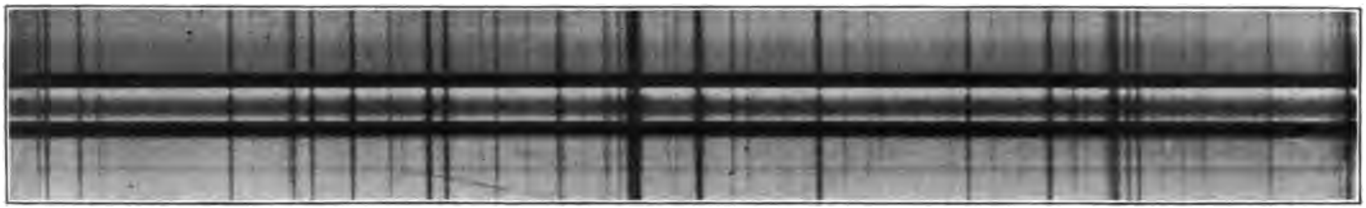


FIG. 2.—Region $\lambda 5285$–$\lambda 5365$

PLATE V

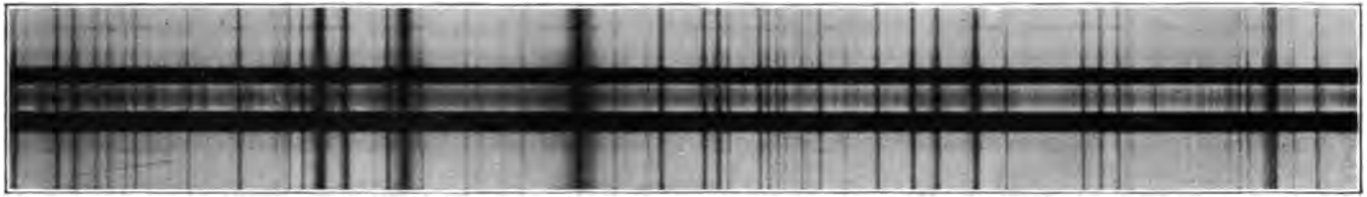


FIG. 1.—Region λ5150–λ5270

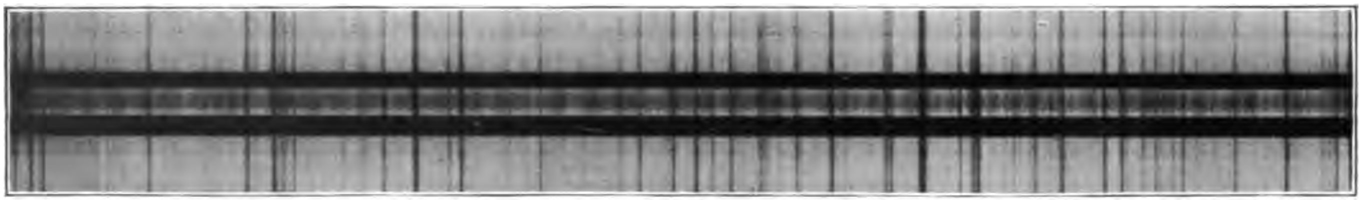


FIG. 2.—Region λ5085–λ5165

Plate IV could exist. The remarkable strengthening of some of the lines of certain elements, and the perhaps even more remarkable reduction in intensity of some of the lines of other elements, gives to spot spectra a very exceptional interest, and should encourage the most careful investigation, both by visual and photographic means.

Our photographs tend to confirm the view expressed by Young, Dunér, and Fowler, that the bright lines described by Young are simply interruptions in the series of dark lines, corresponding to similar interruptions in the general solar spectrum. As for the character of the fine lines in the spot spectrum, to which Mitchell calls special attention, our photographs are not as well suited as visual observations to determine a question of this kind. We hope to return to this and various other questions at a later date.

Of course, it does not follow from our discussion that true bands or flutings do not exist in the spectra of sun-spots. We can only say that we have so far failed to record them, and that many of the so-called "bands" are undoubtedly due to the fine lines shown in our photograph.

Table III contains the detailed results of Mr. Adams' measures, together with the estimates of intensity. The means derived from the separate plates are then compared with Rowland's values. The column R. – M. (Rowland – Mean) gives the differences between the wave-lengths of the lines in Rowland's table, with which we identify our lines, and our mean values, the unit being 0.01 tenth-meter. In the last column the probable identifications with Maunder's bands are added.

A considerable number of blends are included in the table. It will be seen that in almost every such case the line is noted as "broad" in the last column. These notes are taken from the original record books, and indicate that the compound character of the line is shown by its unusual width.

THE CAUSE OF THE DARKNESS OF SUN-SPOTS

In a paper with the above title,[1] Mr. Evershed expresses the opinion that the darkness of sun-spots cannot be accounted for as the result of absorption alone. He cites the explanation of Maunder

[1] *Astrophysical Journal*, 5 244, 1897.

TABLE III

Wave-Length				Intensity				Mean		Rowland		R.−M.	Remarks
L 21	L 20	L 19	L 18	L 21	L 20	L 19	L 18	Wave-Length	Inten.	Wave-Length	Inten.		
5032.56	.54			oo	oo			5032.55	oo	5032.56	oooN	+1	These lines with 5032.09 5032.91 are Maunder's 5033.0
5033.78	.76			o	o			5033.77	o	5033.77	ooo ooo	o	
5034.41	.42			oo–o	oo–o			5034.42	oo–o	5034.43	ooo oooo	+1	Broad
5034.68	.68			oo	oo			5034.68	oo				
5035.10	.09			oo	oo			5035.10	oo				
5042.76				ooo				5042.76	ooo				
5043.08				o				5043.08	o				
5043.51				oo				5043.51	oo	5043.48	ooo	−3	
5044.97	.97			oo	oo			5044.97	oo	5044.94	ooooN	−3	
5046.37				oo–o				5046.37	oo–o	5046.38	oooN	+1	
5047.14				o				5047.14	o	5047.11	ooo	−3	Narrow
5049.39				o				5049.39	o	5049.38	oooo	−1	
5054.23				o				5054.23	o	5054.26	ooo	+3	Maunders 5054.7
5056.15				oo–o				5056.15	oo–o	5056.17	*Fe*oo	+2	Maunder' 5056.7
5056.59				o				5056.59	o	5056.62	ooo	+3	
5059.10	.08			oo	oo			5059.09	oo	5059.11	oooo	+2	Narrow
5059.41	.44			oo	oo			5059.42	oo	5059.41	ooo	−1	Maunder's 5059.2
5060.65				oo–o				5060.65	oo–o				
5061.56				oo				5061.56	oo	5061.58	ooo	+2	
5061.92				o				5061.92	o	5061.88	oo	−4	
5063.71	.71			o–1	o–1			5063.71	o–1	5063.70	oooo	−1	
5064	.03				oo			5064.03	oo	5064.06	oooo	+3	
5065.89				oo				5065.89	oo	5065.89	oooo	o	
5071.32				oo				5071.32	oo	5071.31	ooo	−1	
5081.76				oo				5081.76	oo	5081.76	ooo	o	
5082				o				5082	o	5081.98	ooo ooo	−2	Broad

TABLE III—*Continued*

Wave-Length				Intensity				Mean		Rowland		R.−M.	Remarks
L 21	L 20	L 19	L 18	L 21	L 20	L 19	L 18	Wave-Length	Inten.	Wave-Length	Inten.		
5083.20				o				5083.20	o	5083.20	oooNd	o	
5084.80				oo–o				5084.80	oo–o	5084.80	ooo ooo	o	Broad
5085.03				oo				5085.03	oo	5085.02	ooo	−1	
5086.05				oo				5086.05	oo	5086.08	*Cd* ?ooooN	+3	Maunder's 5086.4
5086.81				o				5086.81	o	5086.79	oooo	−2	
5089.38				o				5089.38	o	5089.39	oooNd ?	+1	
5090.01				oo				5090.01	oo	5090.00	oooo	−1	Maunder's 5090.4
5090.57				oo				5090.57	oo	5090.57	oooo	o	
5091	.48	.48	.48		oo	oo	oo	5091.48	oo	5091.48	oooo	o	Narrow
5092.76	.76.	.77	.77	o	o	o	oo	5092.76	o				Probably Maunder's 5093.0
5092.96				oo				5092.96	oo	5092.98	ooo	+2	
5093.79	.77	.78	.76	o	o	oo–o	oo–o	5093.78	o				Maunder's 5093.7
5095.97	.97	.99	.97	o	o	o	o	5095.97	o	5095.95	oooo ooo	−2	Broad
5096.37	.40			o	oo–o			5096.38	oo–o	5096.36	ooo	−2	Maunder's 5096.2
5096		.49	.51			1	o–1	5096.50	o–1	5096.49	ooo oooo	−1	Broad
5100.66	.63	.63	.63	oo	ooo	oo	oo	5100.64	oo	5100.64	oooo	o	
5101.17	.19	.19	.20	o	oo	oo–o	oo–o	5101.18	oo–o	5101.18	ooo ooo	o	
5101.64	.63	.61	.62	oo–o	oo–o	oo	o	5101.63	oo–o	5101.66	ooo	+3	
5102.16				oo				5102.16	oo	5102.18	oooo	+2	
5102.40				oo				5102.40	oo	5102.40	oooo	+1	
5108.82	.81	.81	.84	o	oo	oo	oo	5108.82	oo	5108.80	oooo	−2	
5109.26				o				5109.26	o	5109.29	oood ?	+3	
5111.16				oo				5111.16	oo	5111.14	oooo	−2	
5111.49	.51	.52	.51	oo	oo	oo	ooo–oo	5111.50	oo	5111.49	oooo ooo	−1	Broad

TABLE III—*Continued*

Wave-Length				Intensity				Mean		Rowland		R.–M.	Remarks
L 21	L 20	L 19	L 18	L 21	L 20	L 19	L 18	Wave-Length	Inten.	Wave-Length	Inten.		
5111.84	.84	.84	.87	0	00–0	00–0	0	5111.85	0	5111.85	000 0000		Broad
5112.34		.36		00		00		5112.34	00				
5112.80	.80	.80	.79	00–0	0	0	0	5112.80	0	5112.82	0000N	+2	
5114.19		.22	.21	0–1		0	0	5114.20	0	5114.20	0000N	0	
5114.70		.70	.71	0		00–0	00–0	5114.70	00–0	5114.68	000Nd?	–2	
5116.33		.27	.26	00–0		00	00	5116.30	00	5116.29	0000 0000	–1	
5116.62		.64	.66	1		0–1	0–1	5116.64	0–1	5116.64	0000	0	Maunder's 5116.9
5117.02		6.98	6.98	0		00–0	0	5117.00	0	5117.01	000 000	+1	
5118.51	.50	.51	.51	0–1	00–0	00–0	0	5118.51	0	5118.53	0000	+2	Maunder's 5118.7
5118.98	9.00	.98	9.01	1	1	0	0–1	5118.99	0–1	5118.99	000Nd?	0	
5119.52	.54	.53	.55	0	00–0	00	00–0	5119.53	00–0	5119.56	000	+3	
5119.95	.93	.93	.92	00–0	00	00	00	5119.94	00	5119.94	0000	0	
5120.26	.30	.31	.31	00	00	00	00	5120.29	00	5120.28	0000	–1	
5121.13		.10	.11	00–0		00	00	5121.12	00	5121.13	0000	+1	Maunder's 5121.0
5121.41				00–0				5121.41	00–0	5121.41	0000	–1	
5122		.39		0	0	0	0	5122.39	0	5122.37	0000 000 000	–2	Very broad
5124.67		.69	.70	0		0	0	5124.68	0	5124.70	000 00	+2	Broad
5125.73	.71	.73	.70	00	00	00	00	5125.72	00				
5126.02				00				5126.02	00	5126.01	0000	–1	
5127.11				00–0				5127.11	00–0	5127.10	0000 00	–1	Broad
5128		.72				0		5128.72	0	5128.72	000 0000	0	Broad

TABLE III—*Continued*

Wave-Length				Intensity				Mean		Rowland		R.−M.	Remarks
L 21	L 20	L 19	L 18	L 21	L 20	L 19	L 18	Wave-Length	Inten.	Wave-Length	Inten.		
5131.12				00–0				5131.12	00–0	5131.10	0000	−2	
5132.32	.34	.37	.37	0	00–0	0	0–1	5132.34	0	5132.34	0000	0	
5133.11	.09	.06	.07	00	00	00–0	00–0	5133.09	00	5133.12	000	+3	
5133.34				0				5133.34	0	5133.36	000	+2	
5134.49		.48	.47	1		0–1	0–1	5134.48	0–1	5134.50	0000	+2	
5134.79		.80	.80	1–2		1–2	2	5134.79	1–2	5134.76	000 0000	−3	Broad
5135.28		.31	.34	1		0–1	1	5135.30	1	5135.31	0000 0000	+1	
5135		.84	.82			00	00–0	5135.83	00	5135.82	000*C*, – 000*C*, –	−1	Broad
5136.65	.66	.65	.66	00–0	00	00–0	0	5136.65	00–0	5136.62	0000	−3	
5138.59	.59	.57	.57	0	0–1	0–1	0–1	5138.58	0–1	5138.60	0000 0000	+2	Broad
5138.97	.95	.96	.96	0	0	0	0	5138.96	0	5138.95	000 0000	−1	Broad
5140.46	.45	.40	.41	0–1	0	0–1	1	5140.44	0–1	5140.44	0000 0000	0	Broad
5141.45	.39	.35	.36	0–1	0–1	0–1	1	5141.40	1	5141.43	000*C*, – 0000	+3	Broad
5143.85	.83	.81	.81	1	1	0–1	1–2	5143.83	1	5143.85	000 00	+2	
5144.21	.24	.20	.20	0–1	0–1	0–1	1	5144.21	0–1	5144.20	0000	−1	
5145.93	.94	.94	.91	0	00–0	00	00–0	5145.93	00–0	5145.91	0000N	−2	Narrow
5148.91	.93	.94	.94	1	0–1	1	1	5148.93	1	5148.93	000 000	0	Broad
5149.66	.67	.68	.68	0–1	0–1	0	0–1	5149.67	0–1	5149.68	0000N	+1	
5149.97	0.01	0.00	.99	0	00–0	00–0	00–0	5149.99	00–0	5149.96	000	−3	
5150		.37	.36			1	0–1	5150.36	0–1	5150.36	00	0	

TABLE III—*Continued*

Wave-Length				Intensity				Mean		Rowland		R.–M.	Remarks
L 21	L 20	L 19	L 18	L 21	L 20	L 19	L 18	Wave-Length	Inten.	Wave-Length	Inten.		
5151.36	.36	.37	.38	00	000	000	000	5151.37	000	5151.34	0000N	−3	Narrow
5151.63	.64			000	000			5151.63	000	5151.63	0000N	0	
5152		.82	.81			00	00	5152.82	00				An unresolved band fills the space between the lines 5154.24 and 5155.30
5156		.54	.52			00	00	5156.53	00	5156.53	000	0	
5157.20	.21	.20	.21	00	00–0	0	00–0	5157.20	00–0	5157.16	0000	−4	
5157.78		.79	.81	00		0	0	5157.79	00–0	5157.78	000–, *C*	−1	
5158.51	.48	.50	.48	000	00	00	00	5158.50	00				Narrow
5158.80	.82	.82	.80	0	00–0	0	0	5158.81	0	5158.83	0000, *C*	+2	
5159.97	.96	.97	.94	0–1	0	1	0–1	5159.96	0–1	5159.95	0000	−1	
5160.39	.38	.38	.40	0–1	0	1	1	5160.39	0–1	5160.42	00N*C*, –	+3	
5163	.11	.11	.09	2	1–2	2	2	5163.10	2	5163.07	000*C*, –	−3	Very broad
5163	.79	.81	.78		00–0	0	0	5163.79	0	5163.76	000*C*, –	−3	
5168		.36	.34			00	00	5168.35	00	5168.36	000Nd?	+1	
5169	.64	.65	.69		000	000	000	5169.66	000	5169.66	0000	0	
5170	.26	.25	.25		000	000	000–00	5170.25	000	5170.27	0000	+2	
5170.74	.80	.80	.80	0	0	0	00–0	5170.78	0	5170.77	000	−1	
5171.20	.20	.21	.20	00–0	00–0	00	00–0	5171.20	00–0	5171.19	0000	−1	
5175.10	.11	.13	.14	0	00–0	00	00	5175.11	00	5175.10	000	−1	
5175.59	.54	.55	.54	0	0	00–0	00	5175.56	00–0	5175.58	000	+2	
5175.92	.93	.94	.95	00–0	00	00	000	5175.93	00	5175.92	000Nd?	−1	
5176.30	.31	.31	.31	0	00–0	00–0	00	5176.31	00–0	5176.30	000	−1	
5178.66	.69	.67	.66	00	00	00–0	00–0	5178.67	00	5178.64	000	−3	
5180		.68	.65			0	0	5180.66	0	5180.66	{ 000 000	0	
5185		.21	.21			00	000	5185.21	000–00	5185.20	0000	−1	
5186			.53				00	5186.53	00	5186.50	000N *Fe*	−3	Broad

TABLE III—*Continued*

WAVE-LENGTH				INTENSITY				MEAN		ROWLAND		R.–M.	REMARKS
L 20	L 20	L 19	L 08	L 21	L 20	L 19	L 18	Wave-Length	Inten.	Wave-Length	Inten.		
5187		.64	.62			00	00	5187.63	00	5187.62	000	–1	
5190		.36	.34			0	00–0	5190.35	00–0				
5190		.74	.72			00–0	0	5190.73	00–0				Narrow
5193		.61	.61			00–0	00	5193.61	00	5193.60	0000 000	–1	Broad
5194		.14	.14			0–1	1	5194.14	0–1	5194.14	0000 000	0	Broad
5198		.51	.52			00	00	5198.52	00	5198.51	0000	–1	Narrow
5199		.79	.79	1	0	0–1	0	5199.79	0–1	5199.77	000	–2	
5201		.78	.82	00	0	00–0	00–0	5201.80	00–0	5201.77	0000	–3	
5203		.65	.67	0	0	0	00–0	5203.66	0	5203.66	000	0	
5211		.03	.02			0	0	5211.02	0	5211.02	000	0	
5212		.43	.44		0	0–1	0	5212.44	0	5212.44	000N 0000	0	Broad

that a spot may be considered as a region of high temperature, where the condensation of carbon (or some similar element) does not take place to the same extent as in the photospheric clouds. The diminished radiation would then be due, according to Maunder, to the lower emissive power of the gaseous contents of the spot. Evershed recognizes, however, the fundamental defect of this explanation, viz., that the radiation from a sufficient thickness of such intensely hot gas would be as great as that from a theoretical "black body," thus actually exceeding the radiation of the photospheric clouds. He endeavors to escape this difficulty by assuming that the maximum of intensity in the spectrum of this gas would be displaced into the extreme ultra-violet. The position of the maximum in the spot spectrum would then furnish the means of deciding between the two views.

Liveing and Dewar made a similar suggestion in 1883,[1] but E. Weidemann pointed out that, although the intensity of a luminous source increases most rapidly in the more refrangible region as the temperature rises, the intensity of the less refrangible region also increases.[2]

Dr. W. E. Wilson, who also believes that the darkness of a sun-spot is principally due to deficiency of radiation rather than to absorption, offers a suggestion advanced by the late Professor Fitzgerald for the purpose of getting over the difficulty. Professor Fitzgerald believed that great convection currents must exist within such a gaseous layer as that seen in a sun-spot, and that these would scatter a large amount of light, and thus prevent it from reaching the surface. Hence the effective radiation would be limited to a layer not deep enough to give the effect of a "black body," and the spot would appear dark.[3]

The evidence brought in the present paper, in addition to that previously furnished by visual observations, leaves no doubt in our

[1] *Phil. Mag.*, 5th series, **16**, 402, 1883.

[2] Ibid., **17**, 247, 1884.

[3] *Monthly Notices*, **65**, p. 325, 1905. Wilson, in another paper, describes an experiment in which the radiation of an arc, in a gas at high pressure, was greatly reduced by the effect of convection currents caused by suddenly releasing the pressure (*Proc. Royal Society*, A **76**, 375, 1905).

minds that absorption is to be regarded as the principal cause of the darkness of sun-spots. A mere reduction of the intensity of the solar light, due to diminished radiation, could not, in our opinion, account for the observed phenomena. In describing his artificial spot spectrum,[1] Wilson states that all lines with nebulous edges are widened, while sharp lines are not affected. In answer to this, it may be said, on the one hand, that the lines which are widened in sun-spots are not all nebulous, and, on the other hand, it frequently happens that certain very faint lines are greatly increased in intensity, while other faint lines of the same element are not affected.

It is true that Wilson, in his recent paper, does not ascribe the widening of the lines in sun-spots entirely to the want of brightness of the gaseous layer below; he considers that the greater depth of the observed vapors of certain elements, such as titanium, whose atomic weight might determine their position between the photosphere and an underlying gaseous layer, would cause the lines of these substances to be specially conspicuous in the spot spectrum. We have already pointed out that all of the lines of such elements are not equally enhanced, but it might be said that this fact can be no more easily explained on the basis of the ordinary absorption hypothesis. We must therefore have recourse to some other test.

The necessary criterion seems to be afforded by certain determinations of the intensity of radiation of sun-spots corresponding to the light of different wave-lengths, made by Mr. Abbot on Mount Wilson during the past summer, as a part of the work of the Smithsonian Expedition. Without going into the details of these observations, which will doubtless be published in full at a later date, it may be said that the radiation of sun-spots, as compared with that of the photosphere, decreases very rapidly with the wave-length. In the infra-red the radiation of the umbra of a sun-spot is but little below that of the surrounding photosphere, whereas at the violet end of the spectrum the relative intensity of the photospheric radiation is far greater.

[1] Wilson produced a dark line spectrum by passing the light from a luminous globe through the fumes of nitrous oxide. A piece of thin paper pasted to the globe cut down the intensity of the light about 50 per cent., and its image on the slit produced a dark band in the spectrum, across which the diffuse lines were widened.

There can be no doubt, as von Oppolzer has pointed out, that the increase of temperature is extremely rapid in passing from the level of the photosphere toward the center of the Sun. Adopting his minimum estimate of an increase of 6000° C. for one second of arc, and applying Wien's law,[1] we find that the maximum of intensity in the spot spectrum would be shifted to a position not far from λ 2300, if the radiation were supposed to come from a region whose mean level is one second below the photosphere. Since Mr. Abbot's observations show that the maximum of intensity, which is at λ 4900 in the spectrum of the photosphere, is shifted in spots far into the infra-red, we might ascribe such a shift, whatever the source of the continuous spectrum, to the great absorption of the gases which constitute the umbra, and perhaps also to their comparatively low temperature. Leaving the question of temperature for discussion in a future paper, we may say that the radiation measures are entirely in harmony with the visual and photographic observations of spot spectra. The greatly increased absorption, shown by the marked intensity of the innumerable lines in the spot spectrum, would undoubtedly produce a decided shift of the maximum toward the infra-red. We therefore believe that the darkness of sun-spots may be sufficiently well accounted for by absorption alone.

1. The equation

$$\lambda \text{ max.} \times \text{abs. temp.} = \text{const.}$$

gives 6000° C. as the temperature of the photosphere, when Abbot's value of 0.49 μ for λ max., and Lummer's value of 2940 for the constant (corresponding to a "black body") are used. If the constant is taken as 2630, determined by Lummer for platinum, the temperature of the photosphere comes out 5700° C. In computing the wave-length of the maximum for a point one second below the photosphere, we have employed these smaller values.

MOUNT WILSON,
December 1905.

SOME NOTES ON THE H AND K LINES AND THE MOTION OF THE CALCIUM VAPOR IN THE SUN[1]

By WALTER S. ADAMS

The importance of the H and K lines of calcium in the study of solar spectroscopy has been growing steadily greater within recent years. Their remarkable behavior over the general surface of the Sun, in prominences and over spots, would make them the most interesting lines in the solar spectrum even if we did not consider the fact that they are the chief, and for many instruments the only, lines which can be used with the spectroheliograph in mapping the surface of the Sun. Accordingly it may be of interest to describe some special studies on these lines which the writer has been carrying on, and to state some of the results obtained.

The spectroscope which has been employed is of the Littrow form, consisting of a 3½-inch (83 mm) plane grating used in connection with a 4-inch (102 mm) lens of 18 feet (5.5 m) focal length. The image-forming instrument, in the case of the majority of the plates, has been a 6-inch (152 mm) lens of 62 feet (19 m) focal length, used in connection with a small coelostat. This gives an image about 7 inches (17.8 cm) in diameter. A few of the recent plates have been obtained with the Snow horizontal telescope, in which an image of the same size is formed by means of a concave mirror. When the spectroscope was transferred to the latter instrument, the modification was introduced of placing the photographic plate above, instead of to one side of the slit, with a view to making any aberration due to the slight tilting of the lens act along the lines instead of across them. The definition, which has always been excellent, seems to remain unaltered. Almost all of the plates have been obtained in the spectrum of the third order, which is bright in this grating, and sufficiently high to give full photographic resolution. The scale in this order is almost exactly one millimeter to the tenth-meter, or about the same as that of the original negatives used by Rowland in his map of the solar spectrum.

[1] *Contributions from the Solar Observatory*, No. 6.

An accurate knowledge of the wave-lengths of H and K in the arc spectrum is essential for any investigations of these lines in the Sun, and here there seems to be considerable discordance among the values given by different observers. The best of these would seem to be:

	K	H
Rowland	3933.809	3968.617
Kayser and Runge	3933.83	3968.63
For the spark between poles of calcium:		
Eder and Valenta	3933.803	3968.638

In order to make these values comparable with the solar spectrum wave-lengths of Rowland's "Preliminary Table," the erroneous correction applied by Rowland to all of his arc standards has to be compensated. The value of this correction as given by Hartmann, after smoothing out Jewell's measures by means of a curve, amounts to −0.010 for K and −0.011 for H. The application of these corrections gives:

	K	H
Rowland	3933.799	3968.606
Kayser and Runge	.82	.62
Eder and Valenta (spark)	.793	.627

In view of these discrepancies, it seemed to me desirable to obtain some measures, and for this purpose I made a number of photographs of the H and K lines, using as a source the carbon poles of an electric arc moistened with a solution of calcium chloride, and in some cases also employing an iron terminal for the sake of the comparison spectrum. The appearance of the H and K lines produced in this way is well known, that of a sharp, narrow absorption line lying upon a strong, bright band whose width depends upon the amount of calcium vapor present. The measures were, of course, made upon the absorption line.

The first four plates were reduced with Rowland's values for the aluminium lines and λ 3973, and Kayser's value for the iron line, λ 3928. The last eight plates were reduced with the use of Kayser's iron standards wholly. As Kayser's and Rowland's systems are

entirely homogeneous, this procedure is evidently quite correct. Each of the values of H and K rests upon two standard lines, and the largest value of a residual found for a standard upon any one of the plates is +0.007. The results of the measures are as follows:

	K		H
	3933.819		3968.630
	.820		.625
	.823		.631
	.820		.632
	.816		.631
	.816		.625
	.819		.629
	.815		.629
	.820		.625
	.815		.630
	.817		.629
	.818		.629
Mean	3933.818	Mean	3968.629

Applying the previous corrections to these values, we find for direct comparison with the wave-lengths of the lines in the solar spectrum:

K	H
3933.808	3968.618

The solar photographs which were measured include some which were made with the slit upon the general disk and others across spots. The approximate position of the slit upon the Sun has been noted in all cases. The narrow absorption line has always been measured, and in a considerable number of cases the bright components as well, although these measures are much more difficult. It is evident, if a is the wave-length of one of these components, and d the difference of wave-length between the absorption line and the second component, that the center of the whole bright line is given by $a+d$.

The following table contains a list of the measures. K_3 is used for the central absorption line, and V K_2 and R K_2 stand for the violet and red components of the bright line, respectively, according to the notation introduced by Hale. The plates are grouped according to the position of the slit on the disk of the Sun, whether near the center, limb, or, roughly, midway between. The method of

reduction followed has been the same as that in the case of the arc spectrum measures, each line depending upon two standards. The largest residual found is less than 0.01 tenth-meter. The plates are given arbitrary numbers, and the letters following the numbers refer to separate exposures in regions of the Sun which lie close together. In a few cases different points along the lines on a single exposure have been measured, and these are denoted by figures in brackets.

MEASURES ON DISK

Plate	K_3	H_3	H_3-K_3	K_2	H_2	H_2-K_2	Remarks
Near Center							
1 a.....	3933.797	3968.615	0.018	3933.798	3968.621	0.023	V K_2=R K_2
b.....	.809	.617	.008	.807	.620	.013	V K_2=R K_2
2 a(1)..	.805	.617	.012	.802	.616	.014	V K_2=R K_2
(2)..	.803	.620	.017	.796	.619	.023	V K_2=R K_2
(3)..	.798	.615	.017	.793	.606	.013	V K_2=R K_2
(4)..	.800	.618	.018	.796	.607	.011	V K_2=R K_2
One-half Center to Limb							
3 a.....	.807	.622	.015	.799	.815	.016	V K_2=R K_2
b(1)..	.793	.601	.008				
(2)..	.800	.616	.016				
c (1)..	.797	.604	.007				
(2)..	.776	.588	.012				
(3)..	.815	.627	.012				
d (1)..	.806	.610	.004				
(2)..	.792	.610	.018				
Near Limb							
4 a.....	.810	.620	.010				
b.....	.813	.620	.007	.798	.617	.019	V K_2>R K_2
5 a(1)..	.810	.626	.016	.805	.622	.017	V K_2=R K_2
(2)..	.803	.622	.019	.810	.625	.015	V K_2>R K_2
b.....	.805	.609	.004				
c......	.808	.611	.003				
6 a.....	.798	.611	.013				
b.....	.804	.609	.005				
c......	.800	.613	.013				
d.....	.801	.607	.006				

MEASURES OVER SPOTS

K_3 and H_3 Bright and Single

Near Center

7 a.....	.809	.625	.016				

			Near Limb				
8 a.....	.810	.619	.009				
b.....	.815	.620	.005				
c......	.808	.611	.003				
			K_3 and H_3 Dark and Narrow Near Center				
9 a.....	.806	.613	.007	.800	.606	.006	
b.....	.799	.610	.011	.789	.606	.017	
c......	.795	.603	.008	.794	.601	.007	
			0.011			0.015	

The most striking feature of these results is the general tendency toward a displacement to the violet. The average wave-length of K, for the measures on the disk, is 3933.802, and of H 3968.612, and the persistence of the direction of displacement among the separate values makes this almost unquestionably real. Taking the values already found for the wave-lengths of H and K in the arc spectrum, the average displacement amounts to 0.006 tenth-meters, which would mean a velocity of approach on the part of the calcium vapor producing the absorption lines of 0.41 kilometers a second. In taking this average, however, it is by no means intended that the conclusion should be drawn that the ranges among the separate plates are accidental. That these are due to actual differences of motion is shown not only by the fact that they considerably exceed the degree of accuracy attained in the measures, but also from a consideration of single plates, such as 3 c. In this plate we find a range of 0.039 tenth-meters for both H and K, between two points at a short distance from one another, and this is visible to the eye in a decided bending and slant of both the emission and the absorption lines. No certain evidence can be found in these observations of any such variation in the motion of the calcium vapor between the center and the limb, as might be expected from a general drift upward in a radial direction. A large amount of material will, however, be necessary before any conclusion can be drawn in regard to this matter.

The result found above, of a displacement of the absorption lines toward the violet, is opposed to Jewell's conclusion that the vapor

producing these lines is descending toward the surface of the Sun. In regard to this matter, he says[1]:

> The narrow central component of the shaded lines shows a descending motion over the solar surface of the absorbing matter producing it . . . . of about a mile a second in the case of the H and K lines. The velocity in the case of the H and K lines is decidedly variable. . . . . These narrow components of the shaded lines are probably produced by meteoric matter falling into the solar atmosphere.

This contradiction of results seems to lie largely in the difference of wave-length assigned to the arc lines in the two cases. Jewell gives the values:

K	H
3933.794	3968.603

It would be of interest to know what standards were employed in the derivation of these values, but no information is given on that subject. That the choice of standards may vitally affect the results is shown by the difference in wave-length amounting to 0.013 tenth-meters assigned by Kayser and by Rowland to the iron line at λ 3928.

The results given by the emission lines, H_2 and K_2, also show a displacement toward the violet, although the measurement of these lines is much more difficult than that of the absorption lines. In this respect they confirm the conclusion formed by Jewell, although no quantitative determinations were made by him. Upon most of the plates which were measured the violet and the red components are very nearly equal; in several the violet is slightly stronger, and in one distinctly weaker than the red component. This last condition is known to be decidedly rare.

The measures given in the above table of bright K_3 and H_3 over spots show some slight indication of a longer wave-length than on the general surface. It would need a much larger number of observations to establish this, however, as the lines are wide and hazy and much more difficult to measure accurately than the absorption lines. The other measures over spots, in which K_3 and H_3 appear as dark lines between bright components, probably belong strictly to the series of measures on the disk. They were made over small spots on which photospheric light evidently encroached sufficiently to produce the characteristic appearance of the lines on the disk rather

[1] *Astrophysical Journal*, 11, 237, 1900.

than the single bright lines which are peculiar to spots. This same effect is found in photographs of spectra of very small spots in the yellow and green region, when very little of the characteristic spot spectrum is likely to be found unless the solar definition is extraordinarily fine.

In a recent number of *Comptes Rendus*,[1] M. Deslandres states some conclusions derived by him from an examination of a number of photographs of the K line. These were obtained with his *spectrographe des vitesses*, an instrument which by means of an interesting attachment is so moved as to give on a single plate a record of a narrow strip of spectrum at a large number of successive points on the Sun's surface. In discussing these plates M. Deslandres says that at the center of the disk the two bright components of K_2 are unsymmetrical, with the red component the narrower. From this displacement of the absorption line K_3 in reference to the emission line K_2 he draws the conclusion that the vapor producing K_3 is descending, and the vapor producing K_2 is ascending. It is evident that this conclusion is by no means justifiable since the displacement of one line in reference to the other indicates only relative motion, and can have no bearing on the question of the absolute motion of the vapor giving rise to either line. The latter can be determined only from comparison with the spectrum from an artificial source, as has been done by Jewell and in this paper.

In stating that at the center of the disk the components of K_2 are unsymmetrical it appears to the writer that M. Deslandres makes too broad a generalization. In the case of each of the plates discussed in this paper which were taken at the center of the disk the components are apparently quite equal. A similar contradiction is found at the limb, where, in M. Deslandres' opinion, the lack of symmetry disappears. Two out of three of the plates which were measured show the violet component of K_2 to be decidedly the stronger. It seems probable that, while an effect like that found by M. Deslandres is perhaps to be expected, the local conditions of the calcium vapor at different points on the Sun's surface vary so much as to mask it completely in many cases. Evidence of this is found in

[1] 141, 7, 377, 1905.

spectra taken with a slit of considerable length; the components vary greatly at different points and often by unequal amounts.

One of the most important conclusions to be drawn from this series of measures is in regard to the relative wave-lengths of H and K. Rowland gives for these two lines in the solar spectrum:

$$\begin{array}{cc} \text{K} & \text{H} \\ 3933.825 & 3968.625, \text{ or } H-K=34.800 \end{array}$$

The values found in this investigation give the following differences:

Arc Spectrum	34.810
K_3 and H_3	34.811
K_2 and H_2	34.815

The last value is, of course, much less accurate than the others, but is certainly confirmatory of them. There is accordingly little doubt that in the Sun the relative wave-length as given by Rowland, of H as referred to K, is in error by about 0.010 units. It is, of course, equally evident that no definite wave-length can be assigned to these lines in the solar spectrum, since the vapor giving rise to them has different motions on different parts of the Sun's surface.

In considering the variations in the position of these lines as due to motion alone, the possible effect of pressure has been neglected. As Jewell has already shown, however, it is clear that the effect of pressure in the region of the solar atmosphere producing the absorption lines, K_3 and H_3, must be extremely slight. In the case of K_2 and H_2 it may be sensible, and partially compensate a still larger shift of these lines in the direction of shorter wave-lengths.

In conclusion, it ought to be stated that a very large amount of observational material will be necessary to determine the laws of motion of the calcium vapor over the surface of the Sun. Even with very powerful apparatus, the measures are delicate and complicated by the changing character of the lines. The value of such determinations toward the interpretation of spectroheliograph results will be very great, however, and similar studies on other lines, notably those of hydrogen, sodium and iron, would assist materially in determining the structure of the Sun's atmosphere.

NOTE ON H_ϵ

On a photograph taken October 27, 1904, with the slit crossing a

group of small spots, the ϵ line of hydrogen appeared as a broad, hazy, bright shade across two of the spots, and a narrow bridge between them. As this is a very rare observation, measures were made on the four separate exposures upon the plate, with the following result:

$$\begin{array}{r} 3970.175 \\ .165 \\ .167 \\ .169 \\ \hline 3970.169 \end{array}$$

The agreement of the separate measures is rather illusory, the line being excessively hazy and ill-defined, as well as a full tenth-meter in width. The result agrees, however, with the value given by Rowland, which is considerably smaller than that found by most eclipse observers.

Solar Observatory,
Mount Wilson, Cal.,
November 1905.

THE FIVE-FOOT SPECTROHELIOGRAPH OF THE SOLAR OBSERVATORY

By GEORGE E. HALE and FERDINAND ELLERMAN

In a recent paper[1] we have described the spectroheliograph designed for use with the 40-inch Yerkes refractor. As stated in this paper, the most satisfactory form of spectroheliograph is that in which the instrument is moved as a whole, while the image of the Sun and the photographic plate are stationary. The first spectroheliograph of this type was constructed in 1893, from Mr. Hale's general design, by Toepfer, of Potsdam, and employed in some attempts to photograph the solar corona without an eclipse, from the summit of Mount Etna.[2] In the case of the Rumford spectroheliograph, it was necessary to produce the motion of the Sun's image across the first slit by driving the telescope tube at a uniform rate in declination, the photographic plate being moved at the same time across the second slit. From a mechanical point of view, such an instrument is not an entirely satisfactory one, but the Rumford spectroheliograph has nevertheless given good photographs, some of which are reproduced in our paper.

As soon as arrangements had been made to erect the Snow telescope on Mount Wilson, it became possible to design, for use with it, a spectroheliograph of the type employed on Mount Etna. We were fortunate in having the assistance of Professor Ritchey and Mr. Pease, whose skill in working out the details of construction has been demonstrated by the very satisfactory operation of the instrument.

A photograph of the spectroheliograph, mounted for use with the Snow telescope, is reproduced in Plate VI. A better idea of the general design may be obtained from Plate VII, which shows the spectroheliograph in our instrument shop before it was completed. It consists essentially of a massive cast-iron base, bearing four short Λ-rails at its four corners, on which the moving part of the instrument

[1] "The Rumford Spectroheliograph of the Yerkes Observatory," *Publications of the Yerkes Observatory*, 3, Part 1.

[2] *Astronomy and Astro-Physics*, 13, 662, 1894.

PLATE VI

The Five-Foot Spectroheliograph Mounted for use with the Snow Telescope

is carried by four steel balls. The cast-iron platform which bears the slits and optical parts has four inverted Λ-rails which rest on the steel balls, but almost its entire weight is supported by mercury, in three tanks formed by subdivisions in the base casting. Wooden floats extend from the lower surface of the iron platform into these tanks, reducing to a minimum the amount of mercury (about 560 lbs. = 254 kg) required to bear the instrument. The motion of this platform with respect to the fixed solar image and photographic plate is produced by either one of two screws of different pitch, driven by an electric motor arranged to give wide variation in speed.

Slits.—The first and second slits represent marked improvements over the slits employed in the Rumford spectroheliograph. They are each 8½ inches (21.6 cm) long; one jaw is fixed, and the other can be moved by a micrometer screw. The second slit can also be moved as a whole across the end of the camera, so as to permit it to be set accurately upon any spectral line after this has been brought near the center of the field by rotating a mirror in the optical train. Both slits are of very massive construction, so as to reduce the danger of flexure. The jaws are heavy castings of bronze, and the guides, in which one jaw of each pair slides, are very accurately made. The slits are so mounted that they can be rotated in their own plane by a screw, thus permitting the first slit to be placed parallel to the refracting edge of the prisms, and the second slit to be made parallel to the spectral lines. The iron castings which carry the slits can be easily removed from the collimator and camera tubes, when it is desired to substitute other slits of different curvature. The clamping screws, and the stops which determine the position angle of the slits, are so constructed that they can be released in a moment, while they define the position of the slits so accurately that no change in adjustment is required when the slits are returned to their places. The collection of slits already provided for the spectroheliograph includes one straight slit and five slits of different curvatures, required for use with either two or four prisms and for different spectral lines. Additional curved slits are constructed as the need for them arises.

The method of correcting the distortion of the solar image, which arises from the use of a straight first slit and a curved second slit,

is the same as that employed in the Rumford spectroheliograph: the curvature is equally divided between the first and second slits, in accordance with a suggestion made by Wadsworth some years ago. It must be borne in mind that this method is effectual only in cases where an odd number of reflections occur in the optical train (see p. 58).

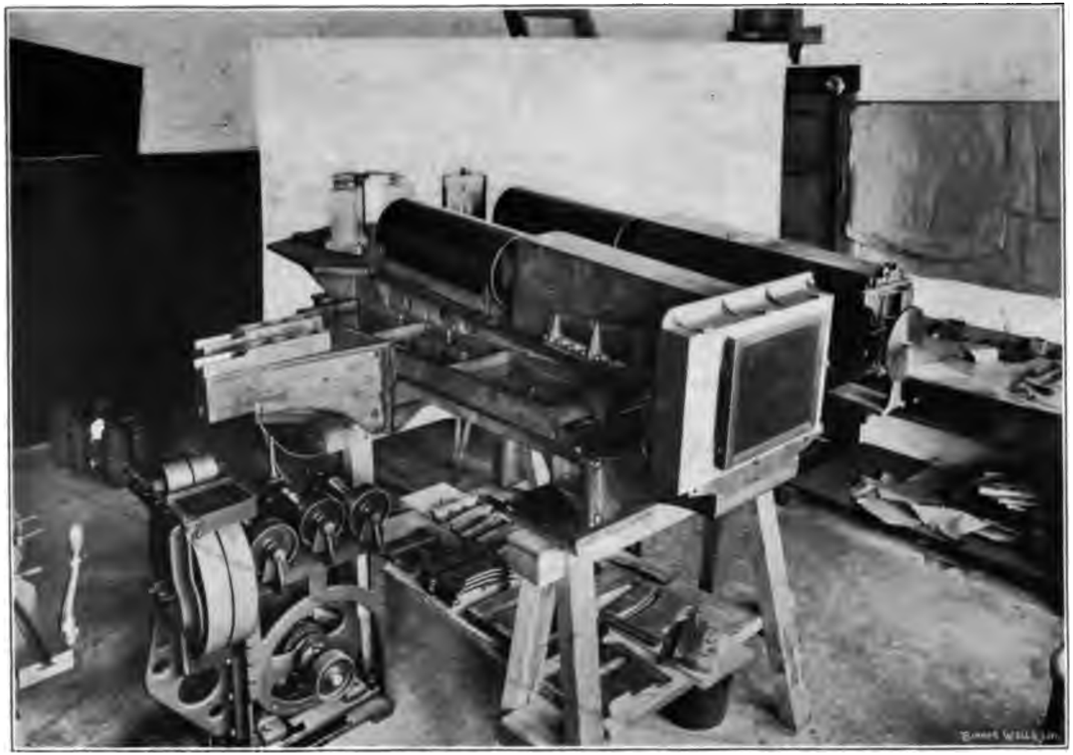
It is important that the second slit should be provided with means of varying its width and changing its position when the photographic plate is in place. For example, it may be desired to make a series of photographs of the flocculi surrounding a sun-spot, corresponding to different widths of the second slit and to different positions of this slit on the H_1 band. For this purpose, as Plate VI shows, the micrometer screws are provided with extension rods, which can be turned from outside the light-tight box that incloses the plate-holder. These extension rods are furnished with micrometer heads, so that the exact position and width of the slit can be read without opening the box.

FIG. 1.—Section of Second Slit-Jaws.

The jaws of the first slit are silver-plated, and when the instrument is in use a light screen of aluminium, pierced by a long narrow window, is mounted a short distance in front of this slit. Without these precautions, as our experience with the Rumford spectroheliograph showed, the heating of the jaws by the large solar image, 6.7 inches (17 cm) in diameter, would cause them to close by expansion during a long exposure.

When the jaws of the second slit are of the ordinary form (beveled on the side away from the photographic plate), there is a possibility, as Mr. Evershed has suggested, that light falling on the beveled surfaces may be reflected through the jaws to the plate. In some experiments made during the past summer with a temporary spectroheliograph, the beveled surfaces were turned toward the photographic plate, to eliminate such reflections. In the present instrument a different plan has been adopted. As shown in Fig. 1, which represents the jaws in section, the lower (dead-black) surface is so formed

PLATE VII



THE FIVE FOOT SPECTROHELIOGRAPH WHEN UNDER CONSTRUCTION

in steps as to eliminate any possibility of appreciable reflection. In work with narrow dark lines, it is very important that all light be excluded from the plate except that which is due to the line itself. Under such circumstances the above precaution may prove of some value.

To cut off the light from the Sun's disk during an exposure on the chromosphere and prominences, circular metallic screens are provided, and mounted on an adjustable support, as shown in Plate VI. Several of these screens, corresponding to different diameters of the solar image, are available.

In order to give an accurate and rapid means of focusing the solar image on the first slit, a disk can be mounted in front of the slit, as shown in Plate VII. The support that carries this disk can be moved by a rack and pinion, and is provided with a millimeter scale, which defines its position with reference to a fixed mark. A piece of fine white cardboard is mounted on the disk, which is set in rapid rotation. By racking the whirling disk back and forth, the Sun's image (seen through dark glasses) can be very accurately focused on the white surface, which does not show such inequalities of texture as trouble the eye when an image is examined on a stationary surface. When a satisfactory focus is secured, the position of the disk is read on the millimeter scale. The distance from the zero position gives a correction by which the concave mirror of the Snow telescope can be set, with the aid of a millimeter scale attached to the rails on which it slides, so as to bring the solar image exactly in focus on the slit-jaws.

Optical parts.—The collimator and camera objectives, which are of the portrait lens type, were made by the John A. Brashear Co. Their aperture is 8 inches (20.3 cm.), their focal length five feet (152 cm). They seem to meet our specifications in every particular, including sharpness of definition, flatness of field, and equality of focal length. They can be focused from the eye-end, by milled heads, provided with micrometer scales (not visible in the photograph). The tubes, of rectangular section, which unite the first and second slits with the collimator and camera objectives, are provided with a very complete system of diaphragms, which seem to do away with all difficulty from diffuse and reflected light. The tubes of the portrait lenses themselves are also lined with diaphragms, which must

be numerous in order to prevent reflection of light from the ends of the long slits.

On account of the desirability of being able to suit the dispersion employed to the work in hand, the prism-train is so designed that either one, two, three, or four prisms may be used. The prisms are of Jena glass, No. O.102, with faces $8\frac{1}{4}$ inches (21 cm) high and $4\frac{15}{16}$ inches (12.5 cm) wide. The angle of each prism is 63° 29′. The arrangement of prisms and mirrors ordinarily employed for work with the calcium lines is shown in Fig. 2. When it is desired to obtain a circular image of the Sun, two slits of equal and opposite curvature are used, and the prism-train is arranged to work with one mirror, as indicated by the solid lines in the figure. In this case, as shown by Newall, each point in the solar image will be drawn out

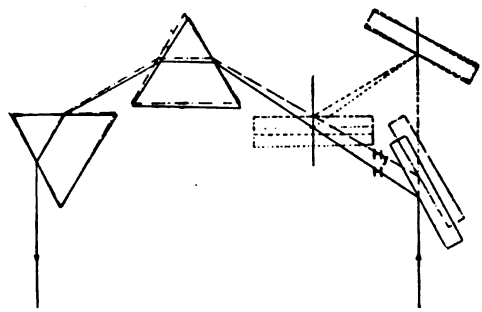


FIG. 2.—Arrangement for Calcium Lines.

in the direction of dispersion into a short line. Under ordinary circumstances the slits are so narrow that the distortion resulting from this cause is entirely negligible. It sometimes happens, however, that important advantages may result (in the case of the H and K lines) from the use of slits so wide that this distortion would be injurious. In such a case, a straight first slit is used with a highly curved second slit, and two mirrors are introduced into the optical train, as shown by the dotted lines. The solar image as a whole will then be distorted, but all of the points in the image will be sharp and well defined. The use of wide slits tends to decrease the contrast, but during the past summer we have obtained excellent photographs of the calcium flocculi and prominences with wide slits, which greatly reduce the exposure time.

In order to bring any part of the spectrum upon the second slit, a mirror immediately in front of the collimator objective can be rotated from the eye-end, by means of a tangent screw. As mentioned above, the final adjustment of the line is made by moving the second slit as a whole. The two prisms are provided with a minimum deviation device, so that they may be brought at once to the position of minimum deviation for any line by setting a pointer at the corresponding reading on a scale. The mirrors may be moved parallel to the optical axis of the collimator, so as to make the light central on the prisms. The position of each mirror is given by a pointer

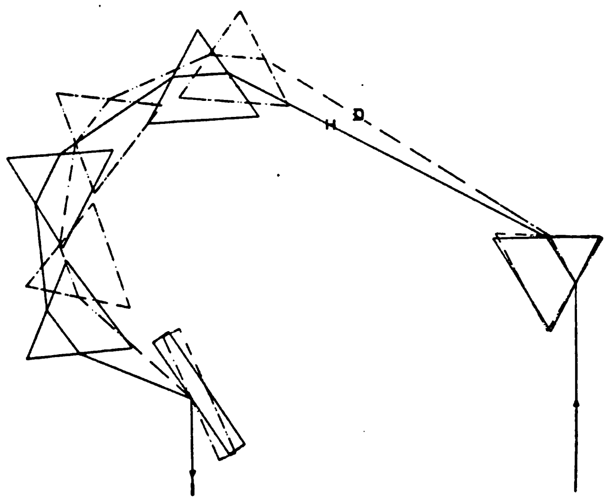


FIG. 3.—Arrangement with Four Prisms.

moving over a millimeter scale. When four prisms are used, the arrangement of the train is as shown in Fig. 3. In this case two mirrors cannot be employed, but they are not needed, since the narrow dark lines used with high dispersion require the use of narrow slits.

Plate-carrier.—As shown in Plate VI, the photographic plate-holder is carried in a light box of cast aluminium, in close contact with the second slit. After the plate-holder has been inserted, the hinged aluminium cover of the box is closed and the slide drawn through a door on the side away from the first slit. This door is then closed and the entire plate-carrier moved forward by rack and pinion until

a conical pin (seen in Plate VI under the iron bracket) drops into a hole in the casting on which the plate-carrier is mounted. In this position the film is almost in contact with the jaws of the second slit.

The plate-carrier is connected with the moving part of the spectroheliograph by a flexible bag, which effectually excludes the light from the plate.

When it is desired to replace the second slit with one of different curvature, the aluminium box can be removed in a moment, by turning the six buttons visible in the photograph.

The driving mechanism.—The moving platform that carries the slits and optical parts of the spectroheliograph is mounted, as already stated, on four steel balls, one inch (2.5 cm) in diameter, running in V-rails. The V's are made of hardened steel, and are ground perfectly true and parallel. As the total weight of the moving parts is approximately 1400 lbs. (636 kg), the system of mercury flotation already referred to was provided to decrease the friction on the steel balls. The result has been extremely satisfactory, the instrument moving with an ease that is surprising when its great weight is considered.

The motion of the platform is produced by either one of two screws, mounted on a strong cast-iron bracket bolted to the iron base. Both screws have hardened and ground end-thrust bearings. The finer screw is of 18 pitch, while the coarser screw, with double thread, is of 3 pitch. The long nuts are split on one side, and can thus be adjusted to take up wear. They are held between the arms of stiff bronze forks, which are connected with the moving platform by steel shafts. The shafts slide freely through cast-iron sleeves bolted to the moving platform. By inserting a conical steel pin, which passes through the sleeve and the shaft, either screw can be made to drive the platform. If neither of the two shafts is fastened to the platform, the instrument can be freely moved across the solar image by hand.

The 1 H.-P. Westinghouse direct-current motor which furnishes the motive power is mounted in a cast-iron frame, shown at the left in Plate VII. By shifting the belt of the motor, any one of three worm gears may be driven by it. Thus either of the screws that move the spectroheliograph may be driven at speeds ranging from 3 to 36

revolutions per minute. The motion is transmitted from the pulleys on the worm-gear shaft to the corresponding pulleys on the heads of the two screws by means of a series of small round belts. Braided fish-line has been found to give more satisfactory results than round leather belting. A single belt of fish-line is sufficient to drive the platform at the highest speed. In practice, however, seven belts of fish-line will be used on each pulley. The driving mechanism is mounted on a pier at some distance below the spectroheliograph,[1] and by moving the idler pulleys shown above the large driving pulleys in Plate VII, the belts corresponding to either the fine-pitch or coarse-pitch screw may be tightened, thus bringing either screw into use.

Current is supplied from a storage battery of 26 cells. The results of the preliminary work indicate that the motion will be very smooth and uniform when all the adjustments have been perfected.

The principal advantages of the new instrument over the Rumford spectroheliograph are: the larger aperture of the collimating and camera objectives, obviating loss of light at the Sun's limb; the possibility of photographing the entire disk with high dispersion; the ease of attaching slits of different curvatures; the possibility of using from one to four prisms, and either one or two mirrors in the optical train; the wide range of speed afforded by the driving mechanism; the elimination of the danger of distortion arising from imperfect synchronism in the motion of solar image and plate; and the ease of manipulation due to the general design and the improvement of details.

RESULTS

The new spectroheliograph, which has been in regular use since October 10, has already yielded some interesting results. On account of the high dispersion of the prisms, and the considerable focal length of the collimator and camera objectives, the $H\delta$ line and the line λ 4045 have been successfully used with two prisms in photographing the hydrogen and iron flocculi. Three photographs of the same region of the Sun, made on November 18, 1905, in quick succession, with the lines λ 4045, H_1 and $H\delta$, are reproduced in Plate VIII. At that time a straight first slit and curved second slit were in use,

[1] In the preliminary work the driving mechanism has been used on a pier north of the spectroheliograph.

and consequently the solar image is distorted. Since the distortion is the same in all three photographs, however, they are strictly comparable with one another. It will be seen that the iron flocculi agree very closely in form with the low-level calcium flocculi. Further remarks on this subject are reserved for a future paper, which will contain the results of comparisons of iron and calcium flocculi now being made with a Zeiss stereocomparator. At present we wish to call attention to the photograph of the hydrogen flocculi, which presents some interesting features.

It will be noticed, in the first place, that the photograph confirms our results obtained with the Rumford spectroheliograph, in showing that most of the hydrogen flocculi are dark, as distinguished from the bright flocculi of calcium and iron. It will also be seen that these dark flocculi correspond roughly in form with the bright flocculi of calcium and iron, though they show certain important divergences. For example, dark flocculi may be found on the hydrogen photograph at points where no bright flocculi appear on the other plates. The H_2 (higher-level) calcium photograph, taken at the same time, also fails to show flocculi at some of these points. These differences in the distribution of hydrogen and calcium in the solar atmosphere will warrant much careful study in the future.

The most interesting feature of the hydrogen photographs, however, which was indicated to a certain extent on some of the plates taken with the Rumford spectroheliograph, is the presence of narrow bright rings, partially or completely encircling certain sun-spots. Fig. 2, Plate VIII, in our paper on the Rumford spectroheliograph, shows a neutral region in the calcium flocculi surrounding the sun-spot; for it cannot be said that this region is materially brighter or darker than the general disk of the Sun in this photograph. In our present plates, however, as may be seen from Fig. 3, Plate VIII (if the reproduction is successful), this region is in some cases distinctly brighter than the general background.

Such rings should be distinguished from the bright eruptive phenomena also frequently shown on hydrogen photographs. The bright eruptions change rapidly in form, whereas these bright rings, which are usually much less brilliant than the eruptions, do not change materially in the course of several hours. They may probably

PLATE VIII

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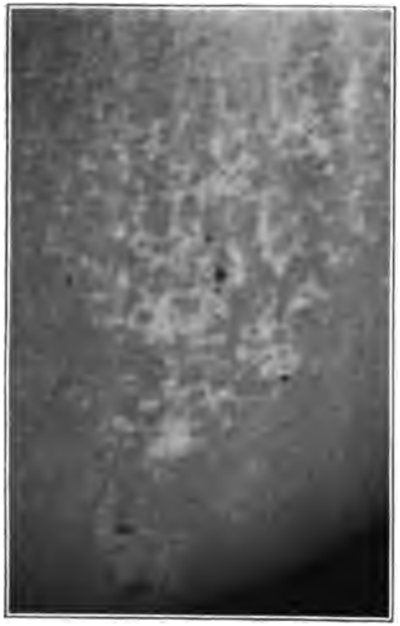

FIG. 1 —Iron Flocculi.
Slit set on $\lambda 4045$.

FIG. 2 —Low-Level Calcium, Flocculi.
Slit set on H_1

FIG. 3.—Hydrogen Flocculi.
Slit set on $H\delta$.

be taken to indicate the existence of comparatively hot regions in the chromosphere closely encircling certain spots. It will be a matter of great interest to study such regions in connection with other phenomena, such as the radial motion of the calcium vapor, and the intensity of radiation as measured with the bolometer. We have already convinced ourselves that the bright rings are due to hydrogen, and are not caused by any effect on the plate of light from the continuous spectrum of underlying faculæ. Indeed, the faculæ are sometimes faint or absent at the very points where the hydrogen rings are brightest.

MOUNT WILSON,
December 1905.

LINE STRUCTURE. I.

By P. G. NUTTING

Spectrum lines for use as wave-length standards, or for interference measurements, must possess the simplest possible structure. They must be narrow, invariant, free from satellites, and easily available. At the National Bureau of Standards the investigation of such sources has been undertaken, chiefly with the echelon grating. A general survey of the available spectra produced under various conditions has indicated the limits within which the choice of monochromatic sources must lie. Succeeding papers are to contain more detailed and numerical data on line structure.

The echelon used was made by Petitdidier and contained thirty plates, each fifteen millimeters thick and with half-millimeter steps. Instead of being clamped and mounted vertically in the instrument, they were laid loosely—to avoid strain—in a horizontal position in a carefully planed, rectangular brass trough. Then, with echelon slit horizontal, a spectrum with lines *vertical* was thrown upon the echelon slit by means of an ordinary monochromatic light apparatus. With this arrangement half the visible spectrum may be observed at a single setting, the prismatic dispersion being horizontal, while that due to the echelon is vertical. With the spectroscope slit opened but two or three tenths of a millimeter, the lines of the echelon spectra appear of ample length for observation, and yet the overlapping of echelon spectra is not troublesome, even in working with the iron arc spectrum. With the ordinary arrangement—both slits vertical—a spectral impurity appears as a satellite. With this arrangement the lines due to an impurity appear longitudinally displaced and are easily detected. Again, in comparing lines from a fluctuating source like an arc, it is an advantage to have them simultaneously in the field of view.

The dispersion of the echelon is such that spectra of different order are roughly half a tenth-meter apart in the green; hence line structure could be studied until lines broadened to this width. The separation of lines per given increment of wave-length is approxi-

mately the same (half a millimeter per tenth-meter unit) as for 21-foot concave gratings, while the (calculated) resolving power is about eight times as great. The narrowest lines and satellites observed appeared 0.005 to 0.01 t.-m. broad.

The Fabry-Pérot and Michelson interferometers used for the further study of the "visibility" and structure of some lines were of the ordinary type with planes made by Petitdidier. Fabry[1] suggested interposing a Fabry-Pérot interferometer between the source and slit of a spectrograph, thus obtaining interference bands in all spectrum lines at once. This arrangement was used in some preliminary work in which about forty arc and Plücker tube spectra were photographed. Only the broadest lines, like those of thallium, sodium, and the lead "arc" lines, fail to show interference bands. Even the lines of the sulphur secondary spectrum show them, while with the echelon they show only diffraction bands.

TYPES OF LINE STRUCTURE

A complex spectrum, like that of the iron arc, viewed with the echelon arrangement above described, shows the widest diversity of line structure. Lines are single, double, triple, broad, narrow, or reversed, and are continually changing from one form to another with every fluctuation of the arc. Apparently any line, even those of thallium, hydrogen, or rubidium, which broaden so very easily, may be obtained single and narrow under proper conditions, but hardly one line in ten remains single and narrow when bright enough to be useful for interference work. Some lines simply broaden and reverse without other change in structure, while others double and become very complex before becoming very broad. It appears quite certain that the violet lines are much more easily affected than lines in the red, at least in arc spectra. The green mercury line λ 5461 appears to be quite unique in the possession of its satellites. Of the hundreds of lines examined, not another one has been observed having so complex a structure when so feebly excited.

PLÜCKER TUBE SPECTRA

Rarefied gases moderately excited show narrow lines of the simplest structure, but with a heavy current or capacity in parallel—if the

[1] *Comptes Rendus*, **140**, 848–851, March 27, 1905.

pressure be greater than 3 or 4 mm—lines broaden, and finally, with a spark in series with the tube, widen into a continuous spectrum, with the peculiar fluted appearance characteristic of spark lines. This broadening effect precludes the use of lines of secondary spectra—for example, the bright line spectrum of sulphur—as wave-length standards. Of the twenty-four elements which may be used in Plücker tubes, not more than seven—the helium group, cadmium, and mercury—promise usefulness as monochromatic sources. The lines of the primary spectra of hydrogen, oxygen, nitrogen, sulphur, selenium, tellurium, and the halogens are too faint and too numerous to be available, while the lines of the secondary spectra are too broad. The lines of sodium, potassium, indium, and thallium are far too broad when of sufficient intensity, while the Plücker tube spectra of zinc, phosphorus, arsenic, and antimony are too faint and difficult to obtain to be considered.

The red hydrogen line appears sometimes single and sometimes double, but even when single and vanishingly faint, is 0.1 t.-m. broad. The yellow sodium and green thallium lines may be obtained as narrow as 0.07 t.-m. When a trace of sodium was put in an iron arc, the lines were obtained as narrow as 0.04 t.-m. and fairly sharp. The red helium line at λ 6678 is extremely sharp and narrow, and free from satellites. The bright yellow line, as well as its faint companion, appear rather broad—0.05 t.-m.—but free from satellites and with well defined edges. The appearance of the bright line suggested unresolved components, and an attempt was made to break it up still further with a Fabry-Pérot interferometer, but without success. The line shows excellent visibility over several centimeters difference of path in the Michelson interferometer. The green line λ 5016 and the blue λ 4472 appear single, broad, and sharp, like the brighter yellow line. Other gases of the helium group were not investigated, but there is no reason to suppose that the lines of their spectra would be too broad or too complex for interferometer work.

SPARK SPECTRA

Sparks between metallic electrodes give lines far too broad for use as monochromatic sources. They are never less than half a tenth-meter broad. The effect appears to depend chiefly upon the

amount of capacity used, and is greatly heightened by the use of another spark in series; that is, it is due to the steepness of the wave-front of the current wave. Inductance weakens the wings produced by capacity, and sometimes channels them, but never reduces a line to a simple structure. Occasional lines will appear to simply broaden out under the violence of the discharge, but ordinarily it is simply a case of the dark background—between spectra of different order—becoming luminous.

Using a small current (0.02 amp.) of low voltage (5000) and low frequency (60) and a minimum of capacity, and electrodes of iron and brass, the spark lines were found to be still broad and diffuse. Lines due to impurities (sodium, for example) occasionally appear fairly sharp on but a faint background, but a number of tests indicated that it is impracticable to obtain narrow lines by introducing impurities into the spark.

ARC SPECTRA

Arc spectra are full of bright sharp lines that very rarely show any satellites, but frequently appear double, triple, broad, or reversed, and are constantly varying from one form to another with every fluctuation of the arc. Characteristic structure and variability are exhibited in the sensitive intermediate stage between single narrowness and broad reversal. Every line shows several forms of structure, and many of them run through an extended gamut of forms. The structure which a line exhibits depends primarily upon its intensity; that is, upon the amount of a substance vaporized and the intensity of its excitation in the arc. But in many cases the mere presence of an alien vapor in the arc is sufficient to alter the structure of a line, aside from any effect on its intensity. These latter effects were investigated only in a few cases, the object of this preliminary research being merely to find out the characteristic forms of prominent lines with a view to selecting lines that remain single and narrow when of considerable intensity.

The arc used was one of from two to eight amperes at 120 volts, usually between ordinary arc carbons. When too sluggish in its fluctuations, a graphite rod was substituted for the upper carbon. When a spectrum was too bright, giving lines of too advanced a

structure, it was reduced by adding ammonium chloride or some metal like silver to the arc to ionize it with other than the substance under investigation.

Lithium.—The red line λ 6708, orange λ 6104, and blue λ 4602 were observed. The red and blue lines show continuous broadening, but the orange line shows a pronounced structure, two to five components on a continuous ground. None of the lines was obtained narrow even in an iron arc, ionized with ammonium chloride.

Sodium.—The D lines appear single, double, triple, broad and channeled or continuous, according to the current and the amount of salt in the arc. They are easily obtained single and not over 0.05 t.-m. broad by using a very slight quantity of salt in an iron arc. They go through the same variations in structure; only λ 5890 is always a little ahead of λ 5896, it broadens more, doubles first, its components are more widely separated, and so on.

Potassium.—The red lines are broad and continuous. The group of four lines at λ 580 all show a trace of structure on a continuous ground. The group at λλ 535, 510, and 495 showed no trace of structure even in an arc of but half an ampere.

Rubidium.—λλ 7811, 6299, 6207, 5724, 5648, 5431, 5436, 4216, 4202 are broad and continuous, the orange group showing a trace of structure, double and triple, on a continuous ground.

Caesium.—The prominent lines λλ 6213, 6010, 5845, 4593, 4555 were found to be broad and continuous with no trace of structure.

Magnesium.—The single green line λ 5529 is easily obtained single and narrow in an ordinary arc having one electrode metallic magnesium, but it broadens and doubles easily, and may even become continuous and structureless. Of the green triplet λλ 5184, 5173, 5167, the first two are usually obtained with double components 0.07 t.-m. apart, and well defined, while the third is broad and single. With a faint current, or on the edge of the arc flame, or with an arc impregnated with sodium, the double lines appear broad and single, but under the opposite conditions they may be obtained continuous, always retaining some semblance of superposed structure, however. The faint blue (λ 4703) and violet (λ 4352) lines appear single and narrow.

Calcium.—The single red line λ 6719, and the group of red lines at λ 650, appear single and narrow, not over 0.02 t.-m. wide, but with rather diffuse edges. The orange line λ 6162 appears double and λ 6122 single, but both are broad and diffuse. λ 5858 is single and narrow, but diffuse. Other green and blue lines—the 559 group, λ 5350, the 526 group, 5189, the 458 group, λλ 4455 and 4435—appear single and fairly narrow, but the strong violet line λ 4227 appears broad and continuous over a whole order, without a trace of structure.

Strontium.—The strontium spectrum is remarkable for the simplicity and freedom from variation of its lines. While in the iron arc spectrum fully half the lines are double when a heavy current is used, only two, λλ 4832 and 4812, of the forty odd strontium lines are double, and but one, λ 4607, is broad and continuous like the lines of the spectra of the lithium group. In the extreme violet, λλ 4216 and 4078 show a trace of structure, double and triple, on a heavy continuous ground. The green line, λ 4962, widens to about 0.1 t.-m. in a heavy arc, but does not double or reverse. The lines appearing single and narrow, even in a strongly impregnated arc of four amperes, are: λλ 6550, 6503, 6408, 6387, 6161, 6121, the group of eight lines at 55, λ 5330, the group at 525, λλ 5156, 4968, 4962, 4892, the triplet at 487, λλ 4855, 4784, 4756, 4742, 4722, and 4678.

Barium.—The barium lines are more variable and complex than the strontium. Scarcely half of them remain single in a strong arc. Each of the five most prominent lines—the red λ 6497, orange λ 6142, green λ 5536, blue-green λ 4934, and the blue λ 4554—appears broad and continuous with two, three, or five components superposed. The sensitiveness of these lines is remarkable. With every slight fluctuation in the arc they vary from single and narrow to the most complex forms. But all five run through the same series of changes, the same as is run through by the yellow sodium and orange lithium lines under the same conditions, and simultaneously, so far as one can judge. The remaining lines may be roughly divided into two classes: those that double or reverse easily, λλ 6596, 6529, 6482, 6451, 6342, 6111, 6063, 5778, 5519, 5423, and those that remain single in a moderately intense arc, λλ 6695, 6678, 6019, 5997, 5972,

5853, 5826, 4903, 4727, 4691, 4579, 4523, 4432, 4403, 4350, 4283, 4131. It is chiefly a matter of intensity as to which of the three classes a line belongs. All the barium lines appear to be alike in physical structure; that is, they all run through the same gamut of changes of form as their intensity is varied.

Titanium.—All the titanium lines observed, about fifty in the visible region, appear single and narrow. Both the metal and the oxide were used in arcs between electrodes of pure graphite and of ordinary arc carbon, but without obtaining any doubling or reversal effects. Several of the brighter lines appeared to broaden slightly when the arc was intense, but never attained a greater width than 0.08 t.-m. The prominent groups at $\lambda\lambda$ 450, 500, 520, and 568 are especially striking with the arrangement of apparatus used.

Cerium.—The cerium lines possess the same character as the titanium; they are all single and narrow, even the bright green triplet at λ 519.

Thorium.—All of the numerous thorium lines observed appeared single and narrow.

Vanadium.—Except the group of blue lines at λ 440, all the vanadium lines appear single and sharp. Six prominent lines of this blue group appear double, but they do not vary in structure with the fluctuations of the arc and could not be obtained single at the limit of visibility.

Chromium.—Half a dozen of the strongest chromium lines twin or reverse in strongly impregnated arcs, carrying a heavy current. The remaining lines are single and narrow. The lines of the green triplet $\lambda\lambda$ 5204, 5206, 5208, are the most variable of all. Other lines showing variable structure are λ 4666, the group at λ 454, and the strong violet lines at λ 43.

Molybdenum.—The numerous orange, yellow, and violet lines are single and narrow; the whole spectrum, in fact, except two—$\lambda\lambda$ 5532 and 5506—of the prominent green triplet. All lines, however, show a tendency to broaden and reverse as the arc flashes out strongly, and for variability the spectrum should be classed just under that of iron.

Tungsten.—No tungsten lines were observed to double or reverse in an arc of four amperes between carbon electrodes fed with metallic tungsten. A few of the brighter red and green lines appear to broaden slightly.

Uranium.—The lines of the uranium spectrum are so excessively numerous and so uniform in intensity that they appear as a continuous spectrum, with perhaps fifty of the more prominent lines superposed. None of the lines shows either doubling or other changes of structure.

Manganese.—The manganese spectrum is a very interesting one, the lines showing a wide diversity in structure and variability. Two bright blue lines, λλ 4823 and 4783, broaden and reverse with each flash of the arc. The lines of the strong orange triplet, λλ 6022, 6017, 6014, are wide (0.10 t.-m.), but do not double or reverse. The two groups of bright lines in the violet, at λ 445 and λ 405, remain single and invariant, as do all the fainter lines throughout the spectrum.

Iron.—The iron lines, like the barium lines, appear to be all of the same character as regards variability. The general gamut of changes which a line goes through as its intensity is increased is as follows: Lines appear of a minimum width of 0.02 t.-m. when first visible; as the line becomes stronger it broadens uniformly, remaining sharp on its edges, to about 0.045 t.-m., when it divides sharply through the center. These twin lines then move apart, each retaining its original narrowness and sharpness of edge, until separated by a sharp dark space, 0.03 to 0.07 t.-m. broad. Then, and not until then, do the twin lines themselves broaden, blur at the edges, and fill in the intermediate dark channels. This last effect is the reversal proper. With an arc of 3 amperes between iron electrodes, eight or more of the strongest lines, λλ 5328, 5270, 4957, 4921, 4384, 4326, 4308, 4271, appear in the twin stage, all others single. At seven amperes these strongest lines are just reaching the last stage of reversal proper, and about thirty of the next strongest lines have twinned. As the arc sputters and flashes out, the stronger lines may be seen to go through the whole series of changes in a fraction of a second.

Cobalt.—Of the cobalt spectrum the same may be said as of the iron spectrum; all lines appear to be alike in character—i. e., they all run through the same gamut of changes—the spectrum of a line depending upon its intensity alone. Here again the violet end appears to be slightly more variable than the red end, but the effect is not greater than might be due to the difference in photometric sensitiveness of the eye.

Nickel.—The nickel spectrum behaves like the spectra of iron and cobalt. The prominent green line λ 5477 is the first visible line to reverse. This and other lines, in reversing, appear to broaden more, with less sharply defined edges than iron lines.

Rhodium closely resembles iron in the character and behavior of its lines. Lines twin (see especially λ 5422 and λ 4375), remaining sharp before reversal proper occurs.

Palladium is more like nickel, the lines broadening with diffuse edges before reversal.

Osmium and *platinum* behave like their chemical neighbors. Half a dozen of the stronger lines of each may easily be obtained doubled and reversed in the flashes of an arc, the upper electrode of which is graphite.

Copper.—Copper lines differ widely in structure and behavior. λ 5782 is nearly always double, while λ 5104, of about equal intensity, never doubles; diffuse lines like λ 4587 show not a trace of structure at any intensity, while other lines, like λ 4651, remain persistently single and narrow. The line λ 5782 twins abruptly when very faint and remains with components sharp and at a constant distance (0.07 t.-m.) apart until just as it breaks down in the reversal proper. Just as this occurs, each of the two components appears to double, but the transition is very rapid and just at the limit of the resolving power of the echelon. λ 5700 triples when faint, and changes only in intensity until it breaks down in complete reversal. The new components appear at distances 0.02 t.-m. from the primary, are about one-fifth as bright and are rather diffuse. But each of these lines may appear with quite different structure. In working with silver, copper was fed into the arc to reduce the silver lines. Then

Cu λ 5700 appeared sharply twinned instead of triple, while λ 5782 was triple with sharp and well-separated components. In a brass arc both lines appeared double, with just a suggestion of a hazy third component in the brighter flashes of the arc. Finally, a brass- or copper-fed carbon arc gave the structures originally described, λ 5782 double, λ 5700 diffusely triple, which the addition of silver changed, first to both lines triple, and then to λ 5700 double and λ 5782 triple. The green group, λλ 5218, 5153, and 5106, is much more sensitive to fluctuations in the arc than the yellow pair. These green lines widen out with diffuse edges until they reverse. When reversed, they show a trace of structure, usually two, occasionally three, components appearing on a continuous ground. The faint companions of λ 5218 appear at first glance as satellites of that line, but may easily be distinguished by their longitudinal displacement. The violet lines are either too diffuse to show structure, or else they behave like the green group.

Silver.—The bright green pair, λλ 5465 and 5209, are alike in structure and behavior. They may be obtained single, but never with sharp edges, from the outer edge of the arc flame, or by filling the arc with some other metal, like copper. In reversing, they first triple, ill-defined components appearing on either side of the primary at a distance of 0.06 t.-m., and of about one-fourth its intensity. Finally, as the line breaks down into a continuous blaze, five components appear superposed upon the continuous background. However, the central primary component remains always the brightest of them all, instead of dropping out as in the case of the yellow copper lines. The blue pair, λλ 4669 and 4476, and the violet pair, λλ 4212 and 4055, appear to be of the same character and behavior as the green pair. They triple as they broaden, and finally reach a five-component stage with bright primary.

Gold.—All of the five prominent gold lines, λλ 6278, 5838, 5230, 5064, 4793, appear single and fairly narrow, in the spectrum from a gold-fed carbon arc, but with extremely diffuse edges. These gold lines exhibit the most gradual falling off of intensity from the center outward of any of the lines observed. They broaden very easily, but show no trace of structure, nor do they reverse in an arc of eight amperes, so intense as to vaporize the gold very rapidly. The

reversal appears to be of the simplest type, a mere broadening and division.

Zinc.—All four zinc lines are rather diffuse, and are usually found double or triple. The blue group of three lines closely resembles in character and behavior the analogous green copper group. The red zinc line λ 6363 is obtained single only when extremely faint. It is usually triple, with diffuse components separated by about 0.08 t.-m. from the central primary, the companion of lesser wave-length being about half as bright as the primary and four times as bright as the companion of greater wave-length. The blue lines, $\lambda\lambda$ 4810, 4722, 4680, are broad and diffuse, and show a trace of structure on reversal.

Cadmium.—The cadmium lines do not differ greatly from the lines of zinc in character and behavior. The red line λ 6438 doubles when very faint, remains double over a wide range of intensity, then breaks down into a continuous blaze that shows a trace of five superposed components. The green, blue, and violet lines triple while faint, with broad, diffuse companions, which soon increase to cover a whole order. When the arc was reduced with silver or copper, these lines appeared to broaden directly without breaking up. Occasionally the green line flashed out double instead of triple, the third component, the companion of greater wave-length, being lacking.

Mercury.—Mercury lines broaden and reverse, showing a decided structure very like the lines of the related zinc and cadmium. By reducing the arc with silver or copper, the mercury lines were obtained in the intermediate stages, showing the structure obtained when the source is a Plücker tube. Yellow λ 5790 appeared with four components: -0.11, 0.0, $+0.13$, and $+0.23$ t.-m. Yellow λ 3769 appeared triple, the faint companion being at a distance of 0.03 t.-m. on either side of the primary. Green λ 5461 was obtained with the well-known three and five satellite structure which in the arc easily goes over into a broad continuous blaze. Blue λ 4358 appeared in the intermediate stage with three satellites: -0.16, $+0.04$, and $+0.20$ t.-m.

Indium.—The blue line is double, with broad and diffuse com-

ponents in the intermediate stage, but easily goes over into a continuous blaze in an arc of three amperes.

Thallium.—The strong green thallium line, λ 5350, is so broad and diffuse that it is difficult to obtain it single in an arc in open air. The line was reduced to a simple double form by adding a large excess of silver to the arc, but remained double down to the limit of visibility. The components are diffuse, are separated by a distance—constant over a wide range of intensity—of 0.11 between centers, and are of decidedly unequal intensity, the component of lesser wave-length being fully three times as intense as the other. As the intensity increases, the fainter component overtakes its companion in brightness, becomes much brighter, and then itself becomes double just as the line goes over into its final stage, exceeding several orders of echelon spectra in width. Using a brass arc, with a small quantity of thallium added, at one stage, strong, well-defined triplets were obtained about 0.09 t.-m. apart. The middle component of this triplet danced about from side to side in the liveliest manner. As the arc flashes up, it attaches itself to the outer component of greater wave-length; as the arc dies down, it leaps to the opposite side, joins with the component of lesser wave-length, and the structure reduces to the doublet first described.

Tin.—The green line λ 5631 and the blue λ 4525 are alike in structure and behavior. When single they are narrow, but with very diffuse edges. As their intensity is increased, they broaden much more rapidly on the side of lesser wave-length, and finally a diffuse component splits off on this side, just as the lines go over into complete reversal.

Lead.—In an ordinary arc of say three amperes, the orange line λ 6002 and the violet λ 4058 appear extremely broad and diffuse with a trace of structure—two or three components—superposed, while the green lines λλ 5201 and 5005 are single and narrow, but with diffuse edges. With an arc of four amperes, the green lines advance to the diffuse structure of the orange and violet lines described above. With a current of two amperes, and with an excess of silver to reduce the lead spectrum, λλ 6002 and 4058 are reduced to a single narrow structure with diffuse edges.

Of the remaining metallic elements, beryllium, boron, aluminium, carbon, silicon, phosphorus, arsenic, and antimony give no arc lines of sufficient intensity in the visible spectrum, while a number of the very rare elements were not available.

An inclosed arc, provided with brass electrodes, was used at low pressures and filled with hydrogen. The substitution of hydrogen for air as an atmosphere was without noticeable effect, even on the sensitive copper lines $\lambda\lambda$ 3700 and 5782. At low pressures all single lines and all the components of double and triple lines appear much narrower and sharper than at atmospheric pressure. But the removal of the atmosphere appears to be without other influence on the structure of lines; λ 5700 is triple, and λ 5782 usually double, occasionally triple as at ordinary pressures.

DISCUSSION

Perhaps the most striking feature of line structure, in contrast with spectral structure, is its variability. The components and satellites of a line vary constantly in number, relative intensity, and position with every slight fluctuation of the source, and often indeed without any apparent cause whatever. And since every line may appear in any one of several forms, we may hardly speak of any line as having a fixed definite structure, even with a minute specification of conditions of production.

A classification of the various structures exhibited by different lines under varied conditions leads to a grouping under a few prominent types.

(*a*) Lines accompanied by faint companions or satellites of the nature of distinct spectrum lines. The yellow helium line is typical, also the green mercury line. Lines of this type are never obtained single, and are but little, if any affected in structure by causes producing a change in intensity.

(*b*) Lines that, originally single and simple in structure, with increasing intensity merely broaden indefinitely, or broaden and reverse in simple reversal if the source is such that absorption phenomena may take place. Many prominent lines are of this type, those of gold being characteristic.

(*c*) Lines that in the intermediate stage twin, with sharp, widely

separated components that recede steadily from each other as the intensity of the source is increased. This structure and behavior are exhibited by the lines of the spectra of iron, platinum, and many related metals. This effect is by no means to be confused with the apparent doubling of (*b*), the ordinary reversal effect; it resembles more the Zeeman effect in its wide, sharp separation occurring abruptly as the intensity is increased.

(*d*) Lines that are triple in the intermediate stage. The single lines first develop wings. These wings detach themselves from the primary, and increase in brightness so much more rapidly than the primary that finally the center of the complex line is relatively dark; ordinary reversal appears to have taken place. All lines which triple symmetrically, so far as I know, reverse in this manner.

(*e*) This is a miscellaneous class, comprising a few lines which broaden, double, or triple unsymmetrically. Single lines sometimes develop unsymmetrical wings, the brighter one being the first to detach itself. Or, in ordinary reversal, a line may divide at one side of the center, the stronger component later subdividing, giving the line a triple structure at one stage. The green thallium line is characteristic of this class.

The phenomena attending reversal have as yet been by no means clearly worked out, and will require much further study; but even from the effects here described it is difficult to see how the old absorption theory can account for types (*c*), (*d*), and (*e*) above. An explanation of these effects appears to require a consideration of the varying modes of vibration of the primal radiators as a function of the intensity of excitation. For instance, in class (*c*), where lines double sharply with receding components, it is not difficult to imagine a radiating system that would give twin, complementary, variable periods when strongly excited; and would not the assumption of elliptical orbits account for the apparent vagaries of unsymmetrical broadening, doubling, and tripling of type (*e*)?

Some relations between line structure and spectral structure may be pointed out. All the lines in those spectra—iron, uranium, and barium, for example—for which no series relations are known, are alike in structure and behavior, the observed structure at any time being a function of the intensity alone. Where series relations are

known, lines of the same spectral series behave alike, but often quite differently from lines in another series. Lines occurring in pairs with constant frequency difference are alike in structure and behavior in each pair, and usually in all the pairs of the spectrum.

The selection of lines and spectra for use (1) as standard wavelengths, (2) as absolute length standards, and (3) as sources in interferometry, can be made only when both structure and behavior are taken into account. The chief general requirement of importance in this connection is that such line or lines must remain single and narrow, as the intensity is varied over a wide range. Lines must then be selected entirely from class (*b*) above; and there are abundance of arc lines, and indeed whole spectra, in which lines remain single and narrow when of ample intensity for the most light-wasteful interferometry.

BUREAU OF STANDARDS,
Washington, D. C.
November 1905.

PHOTOGRAPHIC PHOTOMETRY OF SHORT-PERIOD VARIABLE STARS

BY J. A. PARKHURST AND F. C. JORDAN

During the past two months some investigations have been carried on at this Observatory to determine photographically the light-curves of several stars known or suspected to be variables of very short period. The instrument used was the 24-inch reflector. The plates were Cramer Crown, Cramer Isochromatic, and Seed 27, most of the work having been done with the last named. The method was as follows: During a time either partially or wholly covering the star's period, exposures were made at short intervals on the same plate, the images being separated by moving the plate slightly between exposures. As the double-slide plate-holder was used, the plate could be moved while leaving the star in the same position in relation to the optical axis of the telescope, thus introducing no differential distortion of the star image. The diameters of the images were measured in both right ascension and declination, and from the means the magnitudes were calculated by Charlier's formula, $m=a-b\log D$, which seems to fit most nearly the instrument and Seed plates. For the Cramer Crown, the formula $m=a-bD^{0.9}$ seems better. The exposures were so timed as to give fully blackened images of the faintest stars needed without over-exposing the brighter stars. Details will be given in the discussion of each star. It seems probable that star magnitudes can be determined from the photographic images with a little greater accuracy than by visual methods; at any rate, the photographic method has two important advantages: first, the plate is free from certain systematic errors which seem inherent in visual work; second, any doubtful measures may be repeated at will.

It is thought that the present work possesses three advantages over some previous photographic determinations of magnitude: (1) the excellent definition of the reflector images makes it possible to measure the diameters with considerable accuracy; (2) the measures were made to 0.001 mm under the microscope, instead of com-

paring the images with a scale-plate; this may be said to replace estimates with measures; (3) the great speed of photographic action of the reflector makes it possible to extend the work to faint stars without requiring an exposure which would cover a considerable portion of the star's period, thus avoiding the danger of smoothing out the light-curve. The longest exposures relative to the period of variation were on the variable 14.1904 *Cygni*, six minutes, where the period is three hours, thus using only one-thirtieth of the period.

Announcements have been made lately of a number of variables of very short period, which would be of great interest and importance if the variation proves real. The conflict of opinion in some of these cases between the most careful and skilful observers is very puzzling to the astronomical world, so that any independent method of checking the reality of the variation would be welcome even if it was no more accurate than the visual methods. But if at the same time there is a slight gain in accuracy, the importance is obvious. To test the matter we offer measures of the following stars:

1. The *Algol*-type variable *U Cephei*, the light-curve of which is well determined. (Compare, for example, Yendell's article in the *Astronomical Journal*, **23**, 213, 1903.)

2. The short-period variable *W Ursae Majoris*, which has been carefully investigated visually by Müller and Kempf, who have given details in the *Astrophysical Journal*, **17**, 201, 1903.

3. The new variable 14.1904 *Cygni*, announced by Ceraski in *Astronomische Nachrichten*, **165**, 61, 1904, but not yet confirmed, as far as known to the writers.

4. Barr's variable *32 Cassiopeiae*,[1] which has the provisional number 186.1904, and which has been confirmed visually by Yendell and Hartwig.

The agreement of our results for the first two stars with the well-determined curves will enable the reader to form an independent judgment of the confidence which can be reposed in the confirmation of Ceraski's star and the failure to confirm Barr's variable.

U CEPHEI

The measures were made on plate No. 71 taken with 18 inches aperture on the 24-inch reflector on June 25, 1904, from $9^h\ 11^m$ to $14^h\ 51^m$ Central Standard Time. There were twenty exposures

[1] R U Cassiopeiae in *A. N.* **170**, 69, 1905.

made on the plate, ranging from 1^m when the variable was bright, to 3^m when it was near minimum. The plate was moved half a turn of the declination screw of the double-slide holder between each exposure, except that for aid in identification a whole turn was made after each fifth exposure, and the last exposure was made by a motion in right ascension. Seeing good, bright moon. The diameters of the star images were measured to 0.001mm with the small Gaertner machine, in an east-and-west direction; the mean of Jordan's and Parkhurst's measures were used. The formula used in the reductions was

$$\text{Magnitude} = a - bD^{0.9},$$

in which a and b are constants and D is the diameter expressed in thousandths of a millimeter. The exponent of D, 0.9, was found by trial. The following comparison stars were used, the letter and Potsdam photometric magnitude being taken from Yendell's paper in the *Astronomical Journal*, **23**, 213, 1903:

Star	B.-D.	Magnitudes	
		Potsdam	Photographic
f..................	81°30	8.04	8.04
g..................	81.27	8.53	8.73
d..................	81.22	9.29	9.29

The photographic magnitude of g was deduced from the measures, using f and d as standards.

TABLE I.

320 U CEPHEI

Plate 71, 1904, June 25

G. M. T.	Mag.	Residual	G. M. T.	Mag.	Residual
15 12.0	8.00	0.00	19 19.6	9.10	+0.01
15 43.4	8.17	+0.03	19 45.6	8.95	+0.01
16 00.9	8.22	−0.04	20 04.4	8.74	−0.05
16 20.5	8.34	−0.12	20 16.3	8.68	−0.01
16 37.6	8.72	+0.06	20 28.2	8.52	−0.04
16 59.8	8.84	−0.04	20 36.0	8.44	−0.04
17 20.8	9.10	+0.06	20 44.0	8.38	−0.01
17 39.7	9.18	+0.04	20 50.0	8.36	+0.03
18 02.7	9.15	−0.07			
18 19.2	9.26	+0.03			
18 50±	9.12	−0.07	Mean............... ±0.04 mag.		

Table I shows the results of the measures, the last column giving

the residuals from the smooth curve shown in Fig. 1. The average residual, ± 0.04 magnitude, compares favorably with the best visual measures.

The light-curve yields the following results:

Minimum 1904, June 25, 12^h $20^m.0$ Central Standard Time
Reduction to Sun $-3^m.5$
Heliocentric minimum, 12^h 16^m5 Central Standard Time
or 1904, June 25, 18^h $16^m.5$ Greenwich Mean Time
Magnitude at minimum 9.23

W URSAE MAJORIS

This star, *B.D.* $+56^\circ.1400$ (R.A. 9^h 36^m 44^s, Dec. $+56^\circ$ $2'.46$, 1900), discovered by Müller and Kempf in the course of their photometric work, is a well-known variable of very short period, a few seconds more than four hours. Three plates have been taken here with the 24-inch reflector, having in all thirty-five exposures. The following comparison stars have been used:

Star	*B.D.*	Mag.	Photog. Mag.	R. A. (1855)	Dec. (1855)
a............	$56^\circ.1397$	6.5	6.72	9^h 31^m $3^s.5$	$+56^\circ$ $31'.1$
b............	56.1398	9.0	8.68	9 32 13	+56 50.5
c............	56.1399	8.5	8.61	9 32 27.5	+56 19.5

Details of exposures and calculated magnitudes are given in the table below:

TABLE II

Exp.	Plate 272, Nov. 9, 1905 G. M. T.	Plate 272 Mag.	Plate 326, Dec. 7, 1905 G. M. T.	Plate 326 Mag.	Plate 327, Dec. 7, 1905 G. M. T.	Plate 327 Mag.
1.......	19^h 15^m	8.17	18^h 00^m	7.32	20^h 00^m	7.86
2.......	19 31	7.53	18 15	7.36	20 7½	7.83
3.......	20 44	7.54	18 30	7.30	20 15	7.86
4.......	21 05	7.35	18 45	7.43	20 22½	7.61
5.......	21 20	7.25	19 00	7.56	20 30	7.61
6.......	21 35	7.33	19 7½	7.43	20 37½	7.59
7.......	21 53	7.30	19 15	7.37	20 45	7.57
8.......	22 10	7.24	19 22½	7.32	20 52½	7.47
9.......	22 25	7.48	19 30	7.44	21 00	7.52
10.......	22 40	7.58	19 37½	7.37	21 15	7.32
11.......	22 59	7.91	19 45	7.54	21 30	7.45
12.......	23 20	7.95	19 52½	7.56		
Seeing	fair		very poor		poor	

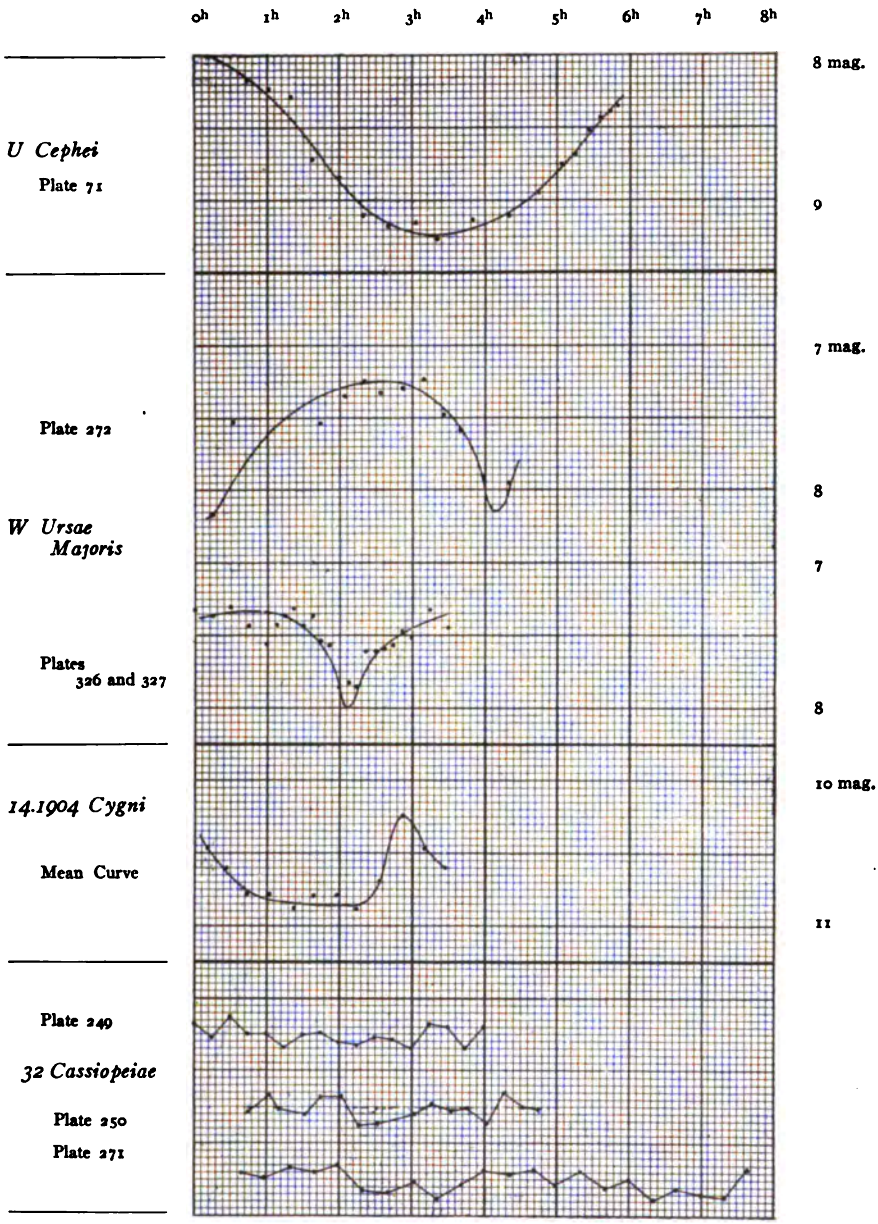

FIG. 1.—Light-Curves.

The interval between exposures 2 and 3 of Plate 272 was caused by a sudden clouding of the sky. Plates 326 and 327 were taken under very unfavorable conditions, because of extreme unsteadiness of seeing; therefore the results from those plates cannot be given the same weight as from Plate 272. Nevertheless, they show the sharp minimum and flat maximum as in Fig. 1, corresponding very closely with the curve obtained by Müller and Kempf from a long series of visual observations.

The comparison with minima calculated from Müller and Kempf's data given in *A.N.*, **167**, 347, 1905, follows:

E	Observed	Red. to Sun	Heliocentric Minimum	Calculated	Residual
1777	1905, Nov. 9, $19^h\ 15^m$	$+1^m.3$	$19^h\ 16^m$	$19^h\ 18^m$	$+\ 2^m$
1945	1905, Dec. 7, $20^h\ 7^m$	$+4.0$	20 11	19 58	$+13$

14.1904 *CYGNI*

R. A. $20^h\ 1^m\ 18^s.46$, Dec. $+58°\ 40'\ 16''.9$ (1900)

This variable was announced by Ceraski in the *Astronomische Nachrichten*, **165**, 61, 1904, with the statement that the range was from 10.7 to 11.6 magnitude, the period about 3.2 hours, and the light-curve resembling the "cluster variables." Our observations confirm the range and the shape of the curve, but are better satisfied by a somewhat shorter period, $3^h\ 1^m\ 26^s.4$ (0.126 day).

The plates taken are listed in Table III.

TABLE III

Number	Date 1905	G. M. T. From	G. M. T. To	No. of Exposures	Seeing
300..........	Nov. 21	$13^h\ 27^m$	$13^h\ 40^m$	2	good
306..........	22	11 35	15 30	16	unsteady
307..........	22	15 33	15 39	1	unsteady, low
313..........	25	12 16	13 41	8	very poor
314..........	26	11 46	13 41	12	good
315..........	26	13 46	15 12	9	good
318..........	28	12 50	13 10	1	good
319..........	28	13 12	13 48	1	good

The positions of the variable and the comparison stars given in Table IV were measured on Plate 318, based on the *A. G.* Catalogue places of the stars *a*, *b*, and *e*. The position of the variable for 1900

was found as given above; the other stars can be located by means of the co-ordinates from the variable given in the table, and also from the chart, Fig. 2.

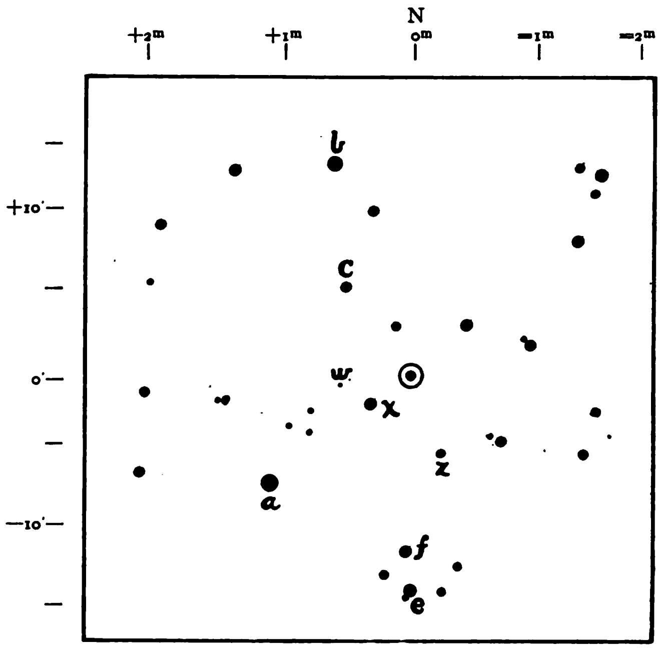

FIG. 2. 14.1904 *Cygni*.
R. A. $20^h\ 1^m\ 18^s.46$, Dec. $+58°\ 40'\ 16''.9$ (1900)

TABLE IV

	B.-D.	Co-ordinates from Variable			Mag.	
		R. A.		Dec.	Photom.	Photog.
z	....	−127′.8	−16ˢ.38	−293′.8	11.02	.....
e	58°2040	− 27.7	− 3.52	−824.6	.....	.....
x	....	+153.2	+19.58	−119.7	10.12	9.99
c	58.2043	+265.5	+33.98	+323.9	10.00	10.14
w	....	+270.6	+34.69	− 50.1	12.1±	.....
b	58.2044	+335.2	+43.23	+794.2	9.26	9.25
a	58.2046	+520.9	+66.53	−441.2	8.66	9.06

It was found by trial that the observations were best satisfied by a period of 0.126 day ($3^h\ 1^m\ 26^s.4$), so that the following ephemeris of maximum was calculated:

TABLE V

Epoch	Calculated		Observed
	J. D.	Calendar	
−9..........	7171.469	Nov. 21, 11^h 16^m	....
−1..........	7172.477	22, 11 38	......
0..........	7172.603	22, 14 28	14^h 25^m
23..........	7175.501	25, 12 2	no max.
31..........	7176.509	26, 12 13	12 00
46..........	7178.399	28, 9 35	......
47..........	7178.525	28, 12 36	12 52
102..........	7185.455	Dec. 5, 10 56	......
103..........	7185.581	5, 13 57	13 00

By the aid of this ephemeris, the observed magnitudes given in Table VI were grouped into ten normal points, giving the mean light-curve shown in Fig. 1. Table VI gives the current number, the plate and exposure number, the Greenwich Mean Time, both calendar and Julian, the epoch number, ΔT, the time elapsed since the preceding maximum, the measured magnitude, and the residuals from the mean curve. The photometric magnitudes were found by the equalizing wedge photometer used on the 12-inch refractor, using as standards the stars in the field of 7220 *S Cygni*, one degree south. From the photometric magnitudes of the stars b, c, and x, the constant b in the reduction formula came out smaller than usual, thus giving a range for the variable of 0.52 magnitude. If the usual value of b were used, the range would be larger, about 0.77 magnitude, agreeing better with the range given by Ceraski. Table VI also contains seventeen measures with the wedge photometer, distinguished by the abbreviation "vis." in the second column in place of the plate number. The photometric magnitudes have been decreased numerically by 0.40, then giving results closely accordant with the photographic, both as to magnitude and shape of the light-curve.

While the separate light-curves agree well in shape, a consideration of the residual column gives the impression that the period is not quite constant, the preponderance in sign being such that it cannot be improved by change either in length of period or in the zero epoch. For this reason the residuals include both the accidental errors of the measures and the effect of apparent change of period. Further

observations will be required to settle the question of the regularity of the change; but if this confirmation is accepted, the star will enjoy the distinction of possessing the shortest known period.

TABLE VI

MAGNITUDES AND RESIDUALS

No.	Plate	Date. G. M. T. Calendar			J. D.	E	Δ T	Mag.	Residual
		1905	h	m					
1.....	300, 1	Nov. 21	13	32	7171.564	−9	0.095	.....	......
2.....	2	21	13	39	71.569		0.100	.....	......
3.....	306, 1	22	11	38	72.485	−1	0.008	10.50	−0.03
4.....	2		11	53	72.495		0.018	10.66	−0.08
5.....	3		12	07	72.505		0.028	10.82	−0.14
6.....	4		12	23	72.516		0.039	10.77	−0.03
7.....	5		12	38	72.526		0.049	10.98	−0.17
8.....	6		12	56	72.539		0.062	10.93	−0.09
9.....	7		13	06	72.546		0.069	10.97	−0.12
10.....	8		13	26	72.560		0.083	11.03	−0.18
11.....	9		13	39	72.569		0.092	11.13	−0.30
12.....	10		13	53	72.578		0.101	10.92	−0.15
13.....	11		14	08	72.589		0.112	10.23	+0.28
14.....	12		14	25	72.598		0.121	10.36	−0.01
15.....	13		14	38	72.610	0	0.007	10.35	+0.11
16.....	14		14	54	72.620		0.017	10.58	−0.00
17.....	15		15	08	72.631		0.028	10.89	−0.20
18.....	306, 16		15	26	72.643		0.040	10.78	−0.00
19.....	307, 1	Nov. 22	15	36	72.650		0.047	10.94	−0.13
20.....	313, 1	25	12	19	75.513	23	0.012	10.53	−0.02
21.....	2		12	30	75.520		0.019	10.62	−0.02
22.....	3		12	40	75.528		0.027	10.69	−0.01
23.....	4		12	50	75.535		0.034	10.63	+0.10
24.....	5		13	00	75.542		0.041	10.75	+0.03
25.....	6		13	13	75.550		0.049	10.48	+0.34
26.....	7		13	26	75.560		0.059	10.19	+0.65?
27.....	8		13	38	75.568		0.067	10.20?	+0.66?
28.....	314, 1	Nov. 26	11	47	76.491	30	0.108	11.76	−0.13
29.....	2		11	58	76.499		0.116	10.32	+0.09
30.....	3		12	08	76.506		0.123	10.34	−0.02
31.....	4		12	18	76.513	31	0.004	10.45	+0.02
32.....	5		12	28	76.519		0.010	10.54	−0.05
33.....	6		12	38	76.526		0.017	10.49	+0.08
34.....	7		12	48	76.533		0.024	10.68	−0.03
35.....	8		12	58	76.540		0.031	10.75	−0.04
36.....	9		13	08	76.547		0.038	10.75	+0.01
37.....	10		13	18	7176.554		0.045	10.79	+0.01

TABLE VI—*Continued*

No.	Plate	Date. G. M. T.				E	Δ T	Mag.	Residual
		Calendar			J. D.				
		1905	h	m					
38.....	11	Nov. 26	13	28	7176.561		0.052	10.85	−0.02
39.....	12		13	38	76.568		0.059	10.86	−0.02
40.....	315, 13		13	48	76.575		0.066	10.66	+0.19
41.....	14		13	58	76.582		0.073	10.75	+0.10
42.....	15		14	08	76.589	31	0.080	10.69	+0.16
43.....	16		14	18	76.596	31	0.087	10.65	+0.20
44.....	17		14	28	76.603		0.094	10.64	+0.18
45.....	18		14	38	76.610		0.101	10.79	−0.02
46.....	19		14	48	76.617		0.108	10.73	−0.10
47.....	20		14	58	76.624		0.115	10.80	−0.36
48.....	315, 21		15	08	76.631	31	0.122	10.36	−0.01
49.....	vis.	Nov. 28	11	52	78.494	46	0.095	10.84	+0.02
50.....			12	06	78.504		0.105	10.85	−0.14
51.....			12	18	78.513		0.114	10.63	−0.18
52.....			12	31	78.522		0.123	10.55	−0.19
53.....			12	39	78.527	47	0.002	10.36	+0.05
54.....			12	50	78.535		0.010	10.31	+0.13
55.....			12	57	78.540		0.015	10.46	+0.09
56.....	318, 1		13	00	78.542		0.117	10.37	−0.20
57.....	vis.		13	09	78.548	47	0.023	10.37	+0.27
58.....			13	27	78.560		0.035	10.52	+0.22
59.....	319, 1		13	30	78.562		0.037	10.59	+0.16
60.....	vis.		13	47	78.574		0.049	10.59	+0.22
61.....			14	12	78.592		0.067	10.69	+0.26
62.....			14	36	78.608		0.083	10.86	0.00
63.....			15	11	78.633		0.108	11.3?	−0.7 ?
64.....	vis.	Dec. 5	13	25	85.559	102	0.104	10.46	+0.27
65.....			13	41	85.570		0.115	10.49	−0.06
66.....			14	34	85.607	103	0.026	10.74	−0.07
67.....			14	48	7185.617		0.036	10.74	0.00

32 CASSIOPEIAE

B. D. $+64°$ 127 = *Hels.-Gotha A. G.* Cat. 983, $1^h\ 5^m\ 10^s.14$, $+64°\ 29'\ 12'.7$, 1900

This star was announced as variable by Barr in the *Astronomical Journal*, **24**, 145, 1904, where the period was given as nearly eight hours and the range 0.4 magnitude. The light-curve given is of unusual shape, the rise and fall being nearly vertical. The variation was confirmed by Yendell in the same *Journal*, page 173, but he found the curve of the usual short-period type, without halt either at maximum or minimum. An added confirmation is given by Hartwig in the *Vierteljahrsschrift*, **40**, 94, 1905, with the statement that the change

is rapid and the maxima and minima can be well determined. In the face of these good authorities, the plates show no change beyond the limit of accidental error, the mean residuals from the three plates being ±0.05, ±0.05, and ±0.06 mag. respectively, while for the three comparison stars the residuals on plate 250 are ±0.06, ±0.04, and ±0.04 mag.

The data for *32* and the comparison stars are given in the following table:

	No. *B. D.*		1855		Mags.	
		Mag.	R. A.	Dec.	Harvard[1]	Photog.
32..........	+64° 127	5.9	$1^h\ 2^m\ 21^s$	+64° 13′.3	5.46	....
B..........	64 129	7.4	1 3 18	+64 13.8	7.46	7.38
C..........	63 149	6.0	1 2 4	+63 25.5	5.48	5.48
D..........	63 147	7.8	1 1 15	+63 24.5	....	6.95

Four plates were taken of this star:

No. 249 1905 Oct. 6 from 13^h 0^m to 17^h 0^m G. M. T. 17 exposures 1^m
No. 250 Oct. 20 from 12 47 to 16 47 G. M. T. 17 exposures 1
No. 271 Nov. 9 from 11 40 to 18 40 G. M. T. 22 exposures 30^s
No. 322 Dec. 7 from 12 1 to 16 1 G. M. T. 16 exposures 45

TABLE VII

32 CASSIOPEIAE (Plate 250)

Mags.: B = 7.38, C = 5.48, D = 6.95, *b* = 10.00

Star		B			C			D			32		
	a	Diam.	Mag.	Res.	Diam.	Mag.	Res.	Diam.	Mag.	Res.	Diam.	Mag.	Res.
1....	8.720	136	7.38	+ 1	214	5.42	− 6	148	7.02	+ 6	208	5.54	+ 2
2....	8.725	137	7.36	− 2	209	5.52	+ 4	151	6.94	− 2	214	5.42	−10
3....	8.570	130	7.43	+ 6	206	5.43	− 5	145	6.96	0	202	5.52	0
4....	8.559	132	7.35	− 2	207	5.40	− 8	141	7.07	+11	200	5.55	+ 3
5....	8.353	124	7.42	+ 5	194	5.48	0	139	6.92	− 4	196	5.43	− 9
6....	7.935	103	7.44	+ 7	176	5.48	0	127	6.89	− 7	178	5.43	− 9
7....	7.622	103	7.49	+12	166	5.42	− 6	118	6.90	− 6	158	5.63	+11
8....	8.739	136	7.40	+ 3	214	5.44	− 4	150	6.98	+ 2	205	5.62	+10
9....	8.210	122	7.35	− 2	188	5.47	− 1	132	7.00	+ 4	198	(5.24)	....
10....	8.054	110	7.34	− 3	178	5.50	+ 2	126	6.98	+ 2	170	5.55	+ 3
11....	8.383	130	7.24	−13	193	5.53	+ 5	136	7.05	+ 9	195	5.48	− 4
12....	8.316	123	7.42	+ 5	192	5.48	0	138	6.92	− 4	190	5.53	+ 1
13....	8.631	136	7.30	− 7	204	5.54	+ 6	146	6.99	+ 3	205	5.51	− 1
14....	8.266	126	7.26	−11	185	5.59	+11	135	6.96	0	184	5.62	+10
15....	8.139	118	7.35	− 2	178	5.54	+ 6	130	6.93	− 3	185	5.40	−12
16....	8.247	...	....	....	190	5.46	− 2	134	6.98	+ 2	188	5.50	− 2
17....	8.168	118	7.45	+ 8	186	5.47	+ 1	134	6.90	− 6	184	5.52	0
Means.....			7.37	± 6		5.48	± 4		6.96	± 4		5.52	±5

[1] Photometric magnitudes from Harvard *Annals*, 24.

TABLE VIII

PHOTOGRAPHIC MAGNITUDES OF *32 CASSIOPEIAE*

	1905. OCTOBER 6			OCTOBER 20			NOVEMBER 9		
	PLATE 240			PLATE 250			PLATE 271		
No.	G. M. T.	Mag.	Res.	G. M. T.	Mag.	Res.	G. M. T.	Mag.	Res.
1.........	$13^h 00^m$	5.43	− 8	$12^h 47^m$	5.54	+ 2	$11^h 40^m$	5.46	− 6
2.........	13 15	5.53	+ 2	13 03	5.42	−10	11 59	5.49	− 3
3.........	13 30	5.38	−13	13 17	5.52	0	12 20	5.42	−10
4.........	13 45	5.50	− 1	13 32	5.55	+ 3	12 41	5.50	− 2
5.........	14 00	5.50	− 1	13 47	5.43	− 9	13 00	5.45	− 7
6.........	14 15	5.60	+ 9	14 02	5.43	− 9	13 20	5.58	+ 6
7.........	14 30	5.51	0	14 17	5.63	+11	13 41	5.60	+ 8
8.........	14 45	5.49	− 2	14 32	5.62	+10	14 03	5.52	0
9.........	15 00	5.56	+ 5	14 47	....	....	14 22	5.64	+12
10.........	15 15	5.58	+ 7	15 02	5.55	+ 3	14 42	5.54	+ 2
11.........	15 30	5.52	+ 1	15 17	5.48	− 4	15 00	5.44	− 8
12.........	15 45	5.54	+ 3	15 32	5.53	+ 1	15 21	5.47	− 5
13.........	16 00	5.60	+ 9	15 47	5.51	− 1	15 42	5.43	− 9
14.........	16 15	5.42	− 9	16 02	5.62	+10	16 00	5.54	+ 2
15.........	16 30	5.45	− 6	16 17	5.40	−12	16 20	5.44	− 8
16.........	16 45	5.60	+ 9	16 32	5.50	− 2	16 41	5.56	+ 4
17.........	17 00	5.44	− 7	16 47	5.52	0	17 00	5.50	− 2
18.........	......	....	....	......	....	....	17 21	5.64	+12
19.........	......	....	....	......	....	....	17 40	5.56	+ 4
20.........	......	....	....	......	....	....	18 00	5.60	+ 8
21.........	......	....	....	......	....	....	18 20	5.62	+10
22.........	......	....	....	......	....	....	18 40	5.42	−10
Means...		5.51	± 5		5.52	± 5		5.52	± 6

These plates were reduced with the formula $M = a - b \log D$. Table VII shows the details of the reductions, giving the photographic magnitudes of the comparison stars at the head of the table, also the constant b of the plate. The constant a differs somewhat from one exposure to another, and is therefore tabulated in the second column. The remaining columns give for each star the diameter in thousandths of a millimeter, the resulting magnitude and the residual from the mean at the foot. The range for 32, the suspected variable, is from 5.40 to 5.63, the mean residual being ± 0.05, practically the same as for the other three stars. Table VIII gives the times, magnitudes, and residuals for the three plates, the results being shown graphically in Fig. 1.

To test the question, raised by Yendell, whether the light-changes are confined to the visual rays which do not strongly affect the ordi-

nary photographic plate; a series of sixteen exposures was made December 7, 1905, on a Cramer Isochromatic plate, extending from $12^h\ 1^m$ to $16^h\ 1^m$, Greenwich Mean Time, with the following results:

Range, from 5.42 to 5.57 mag.
Mean, 5.48 mag.
Average residual, ±0.04 mag.

Excellent seeing gave better images and smaller residuals than usual. The plate, therefore, fails to confirm this hypothesis.

YERKES OBSERVATORY,
December 1905

MINOR CONTRIBUTIONS AND NOTES.

REPLY TO RECENT STATEMENTS BY M. DESLANDRES[1]

I regret exceedingly the necessity of discussing a question of priority, but the repeated statements of M. Deslandres leave no alternative. My reply, however, will be brief.

I am quite content to leave the question of priority in the use of the spectroheliograph to the judgment of those who are acquainted with the facts. In 1894 the French Academy of Sciences awarded me the Janssen medal for the construction and use of the first successful spectroheliograph. In the statement of the reasons for the award (*Comptes Rendus*, **119**, 1068, 1894) no reference is made to M. Deslandres. This might reasonably be considered to settle the matter. However, if confirmation of the opinion of the Academy was needed, it has since been supplied by the award of the Rumford, Draper and Gold Medals of the American Academy of Sciences, the National Academy of Sciences, and the Royal Astronomical Society, respectively. In each case the first successful application of the spectroheliograph was named as the principal reason for conferring the medal.

Although M. Deslandres did not use a spectroheliograph until more than a year after my first successful work with this instrument at the Kenwood Observatory, his observations of the *spectra* of the calcium flocculi were commenced in 1891, almost simultaneously with my own investigations of these spectra. Before 1893, when he also obtained a spectroheliograph, which he has since used with marked success, M. Deslandres devoted special attention to a study of the K line in successive sections of the Sun's disk. The *spectrograph* employed for this purpose was moved a short distance between each exposure, but the exposures were made when the instrument was at rest, and the resulting photographs are photographs of *spectra*. This method is extremely useful, as it gives the means of determining the motion of the calcium vapor in the line of sight at many points on the disk, and in the chromosphere and prominences surrounding the Sun. But a spectrograph thus employed is in no sense a spectroheliograph, although a wide second slit limits the spectral region photographed to the K line and a few lines in its immediate neighborhood.

[1] See *Bulletin Astronomique*, August 1905, and various papers in the *Comptes Rendus*.

Of course, a spectroheliograph can be used to observe or photograph spectra: both solar and stellar spectra have been photographed with our new instrument on Mount Wilson. But when employed for such work, a spectroheliograph is for the time being a spectroscope or spectrograph, since the principle of continuous relative motion of solar image and slit, essential in a spectroheliograph, is lacking. Photographs of the K line in successive sections of the disk were made at the Kenwood Observatory in 1891, before the spectroheliograph was completed; they are still frequently taken in connection with our other solar work.

As I have given the fullest recognition in my papers to those who preceded me in suggesting the principle of the spectroheliograph, including Professor O. Lohse, who actually built and experimented with such an instrument, I see no reason why I should be suspected of a desire to obtain credit properly due M. Deslandres.[1]

[1] M. Deslandres complains (in the *Bulletin Astronomique*) that his papers have not been published in the *Astrophysical Journal*. He alone is responsible for this, as the editors have neither been favored with his manuscripts nor informed of his desire for such publication.

GEORGE E. HALE.

SOLAR ECLIPSE OF AUGUST 30, 1905

The eclipse observers from Kirkwood Observatory, Indiana University, Bloomington, Indiana, were located at Almazan, Spain, a small town northeast of Madrid in the Province of Soria. The party consisted of Professor W. A. Cogshall, of Indiana University, Messrs. E. C. Slipher, F. A. Crull, and C. J. Bulleit, students of the university, Professor A. F. Kuersteiner, Mrs. Miller, and myself. We were assisted, in the manipulation of our instruments on the day of the eclipse by Mr. and Mrs. Charles W. Thompson of California, and Señores Francisco Jodra, Louis Nebot, Victor Jiemenez, and Esteban Milla, of Almazan. The approximate position of the station is $\phi=41^\circ\ 30'$, $\lambda=13^m\ 56^s$ W. of Greenwich.

The observations planned were: (1) Photographs of the corona; (2) a photographic search for intra-mercurial planets; (3) a photograph of the spectrum of each of the flashes, and a photograph of the spectrum of the corona during totality.

The equipment for photographing the corona consisted of four cameras. The diameter of the objective of the principal one is nine inches and its focal length is sixty feet. This instrument was mounted horizontally and fed with a coelostat. A light-tight tube, the outer and inner walls of which were of white canvas and building paper respectively, and which were

separated four inches, led from the objective to a dark room in which the plates were exposed. Neither the plates nor the lens was in contact with the tube. The entire instrument was covered with an A tent of white canvas. The plate-holders containing the plates were fastened to a large hexagon, which the operator could revolve at will upon an axis which was parallel to the Earth's axis. It was provided with a stop which enabled the operator to bring the plates for the successive exposures quickly and accurately into position. All the slides had been drawn from the plate-holders before totality began. The hexagon, as well as most of the mechanical parts of the coelostat, was designed and constructed by Professor Cogshall. Six exposures were made in this camera, of duration one-half-second, two seconds, forty seconds, one minute, fifteen seconds, and one-half second. The plates used were Seed's 27, Gilt Edge, heavily backed. Four exposures were made in a camera having an objective of four inches diameter and of fifty inches focal length. Five exposures were made with a portrait lens of aperture five inches and focal length twenty-eight inches, and three with an old tintype lens of eight inches focal length. The plates used in these cameras were either Seed's 27 or lantern-slide plates. These cameras, together with a spectroscope, were mounted on a polar axis.

The weather on the day of the eclipse was disappointing. For two hours before totality the entire sky was covered by light, though unbroken, clouds. At the time of totality, however, the clouds in the immediate vicinity of the Sun appeared to break away, and the inner corona shone through light, drifting clouds. No clear sky was visible, however, within several degrees of the Sun, neither *Mercury* nor *Regulus* could be seen from this station. During the morning a moderate wind prevailed, the general direction being W. N. W. The first contact was, neglecting seconds, at 11:41. The weather conditions during the eclipse, as observed and recorded by Mr. Thompson were as follows:

Local M. Time	Tempera-ture	Direction of Wind	
11:41....	First	contact	Very slight wind
12:00....	18°.5 C.	N. W.	Very slight wind
12:15....	18.2	N. W.	Very slight wind.
12:30....	17.1	W. by S.	Wind dying away
12:45....	16.1		No wind
12:59....	Totality	begins	No wind
1:03....	Totality	ends	No wind
1:06....	15.0	S. W.	Very slight wind
1:15....	15.0	W.	
1:30....	15.5	W.	
1:45....	16.0	W. N. W.	Wind increasing
2:00....	16.5	W. N. W.	Brisk wind
2:15....	17.2	W. by N.	Brisk wind
2:21....	Eclipse	ends	

Considering the weather conditions, our plates are very satisfactory. The shortest exposure, showing the prominences, suffered very little. The very bright group on the eastern edge of the Sun is particularly well defined, and the negatives made of it with the long-focus camera hold a wealth of detail. The longer short exposures with the long-focus as well as the short-focus cameras show considerable coronal detail, while the longest exposures have that part of the corona uncovered by the clouds much over-exposed, while the clouds made it impossible to register any extended streamers. All the plates lack the definiteness that would have resulted from good seeing. The longest extension of the corona that we obtained was about three-fourths the Sun's diameter.

The apparatus used for the search for intra-mercurial planets consisted of six cameras of 136 inches focal length, four of which had an aperture of three and one-half inches, and two an aperture of three inches All were mounted on the same polar axis. They were mounted in pairs each pair covering in duplicate a region six and one-half degrees square, so that the three pairs covered in duplicate a region along the Sun's equator twenty degrees long and six degrees wide. By a series of experiments we had found that a plate exposed in one of these cameras for three minutes and forty-five seconds, at a time when the sky was as dark as it was estimated it would be at the time of totality, though fogged somewhat by the skylight, would show more and fainter stars than if exposed for a shorter time. We had made exposures varying from one to four seconds, in the vicinity of *Regulus*, when it was near the meridian, beginning just after *Polaris* was visible to the eye. We decided to expose the plates in these cameras for three minutes and twenty seconds. These plates are pretty heavily fogged, as one would expect from a sky covered with bright clouds, but not so badly as to obscure faint star-images. I believe that a plate of the sensitiveness of the Seed's 27, which we used, can be exposed three minutes without serious fog at a time of a total solar eclipse. Our sky was so cloudy that it is unreasonable to expect star-images on these plates. We examined two of them hurriedly (the ones on which *Regulus* should have appeared), but found no star-images. The photograph of the corona on one of the intra-mercurial plates showed longer extension than on any other plate we exposed—due perhaps to the shifting of the clouds during the long exposure.

The corona impressed me as being brighter than in 1900. The effect on the clouds of the light from the eclipsed Sun was peculiarly striking, and from a spectator's point of view was very beautiful.

JOHN A. MILLER.

KIRKWOOD OBSERVATORY,
Bloomington, Ind.
November 9, 1905.

DIFFRACTION GRATING REPLICAS

SECOND NOTE

In a previous paper[1] the writer described the process in use by him for the manufacture of replicas of Rowland's plane diffraction gratings. The present note is a description of a modification of that process, which offers a simplified method of producing good casts.

The original grating is flowed with the amyl acetate collodion and dried in the manner previously described; it is then placed in distilled water until loosened by contraction, and wiped dry. The stripping is performed as usual, and the edges of the cast are trimmed with sharp scissors close up to the ruled surface. This trimming should be done while the replica is held by the forceps, as it is strongly electrified by the stripping, so that minute particles of dust are attracted to the surface of the cast, and adhere thereto, being removable only with difficulty. A perfectly clean and polished glass plate is then flooded with filtered distilled water; and, while the plate still holds a little pool of liquid, the film is gently lowered into contact, carefully centered, and the plate is tilted up. A very gentle even pressure by the velvet rubber frees the cast from surplus water, and the edges are immediately cemented.[2]

The mounting may be either face up or down, as may be desired.

After the edges have been cemented down, the mounted replica may be dried by heat, beginning gently and increasing gradually until a temperature of about 75° C. is reached. In this way the film of water between the glass and the replica is driven off, the film being slightly porous.

If the replica has been mounted face down, it may readily be cemented under a covering glass, following the idea advanced by Ives. Care must be taken, however, that no particles of dust or other foreign substance

[1] *Astrophysical Journal*, **22**, 123, 1905.

[2] Since the writing of this present note there has come to hand *Nature* of November 23, 1905 (**73**, 79) containing a brief article by Mr. Thorp, somewhat in the nature of a reply to my former paper. In this article Mr. Thorp states that he strips and mounts "in a similar manner to Mr. Wallace, but leaving out the gelatin coating, which in my [his] opinion is quite unnecessary." He does not indicate whether or not any other medium is used in this connection.

This idea of mounting by the water method first occurred to the present writer about one year ago and some slight amount of experimental work was performed thereon at that time. However, in the beginning of September, 1905, the work was again taken up and carried through to completion in October; a written statement of the process was made and attested on November 2. In the event of further information confirming the similarity of this water method with that pursued by Mr. Thorp I cheerfully accord to him the priority of use of this process.

have found a lodgment either between the glass and the replica, or in the film itself during the drying, as they will inevitably cause trouble by puncturing the replica and allowing access to the cementing balsam, which, gradually working through the most minute hole, and filling up the grooves, destroys the grating.

Since the publication of the previous paper the author has been informed that the deterioration of the Ives grating alluded to therein is due to this cause, and another grating since obtained shows no sign of deterioration. A correction is also due with reference to Ives' patent, as it now appears that no patent was applied for. The previous statement was based upon information the writer had reason to regard as authoritative.

In mounting by what may be termed the water method, in contradistinction to the former gelatine method, one eliminates at once the very slight difference in refractive index between the replica and the mountant; true, the difference still exists between the replica and the glass itself, but this may be readily overlooked. Experience has shown that, although theoretically open to objection, yet practically, so far as definition is concerned, it is an entirely "negligible quantity." In any event, the similarity in refractive index between the film and mountant (or cement), when adjusted for light of certain wave-length, will not be similarly identical throughout the spectrum. In this connection it may be noted that if a replica be mounted face down upon the gelatine-coated glass, and dried, approximation to the refractive index of the replica is so close that in ordinary daylight the grating effect disappears, and diffraction colors are entirely absent. If examination be made, however, in a spectroscope, with a wide slit and a concentrated beam of light, then very faint first-order spectra are discernible.

Further experimental work was undertaken with the object of determining whether the shrinkage effect was complete with the first part of the process (the stripping) or was continued during the course of the drying. The result of these experiments confirm the latter view.

Measurements were made upon replicas taken from a four-inch and two-inch grating, respectively, which were stripped and mounted under varying conditions, viz.: (1) preliminary bath in water, "sprung" off, and peeled dry; (2) floated off entirely under water; and (3) with prolonged soaking in water. The measurements were made (*a*) while wet, (*b*) partially dry, (*c*) thoroughly dry; (*d*) dried by heat; and (*e*) at normal temperature; (*f*) water mounting and (*g*) gelatine mounting; also (*h*) water mounting, cemented edges, (*k*) water mounting, uncemented edges.

Mean results show that there is a measurable contraction during the drying of 0.016 mm in 35.0 mm.

The particular benefit, therefore, arising from the use of a preliminary coating with gelatine, lies in the fact that once the replica film is mounted thereon it dries without further shrinkage, the gelatine itself drying on glass without contraction in area.

This latter point was determined separately by a series of measurements, for which the writer takes pleasure in acknowledging his indebtedness to Miss F. A. Graves. These measurements upon wet and dry gelatine films, were made with the object of determining any positive shrinkage between the two states. The results obtained show that there is no measurable difference observable, the actual mean being

$$\text{wet} = 7.030 \text{ mm}$$
$$\text{dry} = 7.028 \text{ mm},$$

the difference of 0.002 mm obtained being less than the probable error in setting.

In a series of experiments made upon the influence of temperature upon the collodion film during the time of "casting," it was found that an increase over 21° C. would cause the replica to dry with a more or less matt or reticulated surface. This reticulation increases with the temperature. Lower temperatures varying down to 6° C. appear to exercise no influence upon the film.

Contrary to expectation, a pressure of 200 lbs., continued for ten days, appears to have no direct effect upon the replica. It was supposed that such a continued pressure would result in either a flattening of the ruling, or at least in a changed shape of groove. Careful examination in a spectrophotometer, however, does not show any difference between the half which was subjected to pressure, and that which was not, each half being covered by opaque paper, respectively, when tested.

Through the courtesy of Mr. T. Thorp, of England, the writer has been presented with a grating replica from a 14,438 ruling, and in a letter accompanying the same is informed that the present method of preparing and mounting the casts has been much improved from that in use by him formerly, the air-bubbles (referred to in my former paper) being now entirely eliminated. The replica certainly bears out the statement, being very free from such imperfections and presenting a very clean and brilliant appearance. Mr. Thorp further states that he does not use a preliminary coating with oil before flowing the grating, but makes use of a method

"very little different from" that described by the writer in his previous paper.[1]

[1] Information upon this point was taken from an account of patent specifications (No. 11,466, 1899 T. Thorp) dealing with an improvement on Professor R. W. Wood's diffraction process of color photography, in which occurs the following statement: "A method, non-photographic, of reproducing gratings by smearing the original with a thin oil, such as watchmakers use, and pouring a celluloid solution upon it, allowing it to dry and pulling it off, is also claimed" (*Photography*, August 2, 1900, p. 514).

ROBERT JAMES WALLACE.

YERKES OBSERVATORY,
December 15, 1905.

NOTICE

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric, and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed.

Authors are particularly requested to employ uniformly the metric units of length and mass; the English equivalents may be added if desired.

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THE PERIODICITY OF SUN-SPOTS

By ARTHUR SCHUSTER

I have recently obtained some results which seem to bring us a step nearer to the elucidation of the problem of sun-spot variability. My investigations will shortly be published in full, and I may therefore confine myself at present to a brief statement of the results.

The method used in the reduction of the statistical data has been described in previous publications, but a few words of explanation may assist the reader in forming a judgment on the value of the results obtained. Briefly speaking the method consists in analyzing any regular or irregular disturbance by a process of calculation which operates on it exactly as a spectroscope operates experimentally on a luminous disturbance. Such a luminous disturbance emanating for instance, from a red-hot body would, if we could examine it before it enters the spectroscope, present to us an extremely irregular appearance, and at first sight it would probably not be possible to distinguish it from a similar disturbance emanating from a white-hot body, or even from a gas radiating a number of homogeneous waves. The spectroscope in analyzing the light gives us the means of representing diagrammatically the intensity of radiation corresponding to any wave-length, and such a diagrammatic representation is of use to us even when the spectrum is "continuous," inasmuch as it allows us to determine the distribution of intensity which is the characteristic property of the radiation.

By a process depending on Fourier's theorem we may do by calculation for any variation precisely what the spectroscope does for a luminous vibration. I obtain in this way a diagram represented by a curve drawn with periodic times or frequencies as abscissæ, and having as ordinates numbers proportional to the sums of the squares of the two Fourier coefficients. This sum I call the "intensity" of the period, and the whole diagram is called the "periodogram." I must lay special stress on the fact that I consider the method adapted to pick out the characteristic properties of a variation apart from any homogeneous constituents which it may possess. The climate of a locality would, for instance, in my opinion be represented in the clearest and most concentrated manner if the chief meteorological elements, such as rainfall, barometric pressure, and temperature, were represented in the form of the periodogram.

If the variation is such that homogeneous variations are mixed up with irregular changes corresponding to the continuous spectrum, the method advocated is probably the only one which can give decisive results, especially in connection with a theorem expressing the probability that the periodic variation is not of an accidental nature. The optical analogy is perfect, even to the extent that the periodogram shows all the defects due to incomplete resolution, such as the "diffraction bands" on either side of a true homogeneous period. To separate homogeneous from non-homogeneous variations, high resolving power is necessary, as in the observations of chromospheric lines. Resolving power in optics is due to the number of complete periods which at any time affect the disturbance at the focus of the observing telescope, and in precisely the same way resolving power in the periodogram is directly proportional to the number of periods included in the Fourier analysis. Hence the importance of using observations extending over as long a range of time as possible.

After these preliminary remarks, I turn to the main object of my communication. The data used were Wolf and Wolfer's sun-spot numbers, which give us sufficient information from the year 1749 to the present time. I have in addition used, wherever possible, the measurements of areas which for each synodic revolution of the Sun have been collected by the Solar Physics Com-

mittee of the British Board of Education from the year 1832 onward, and the areas measured from photographs at the Greenwich Observatory for each day of the year since January 1, 1883. I have convinced myself that these series form a sufficiently homogeneous whole, and that Wolf's sun-spot numbers may with sufficient accuracy be made directly comparable with the measurement of areas after multiplication with a factor which is found to be nearly constant.

The whole of the observations were treated collectively, but the complete interval of 150 years was also divided into two nearly equal portions, which were separately examined. At first sight the results obtained by a comparison of the two intervals of 75 years was exceedingly puzzling. While the observations beginning with about 1826 showed a nearly homogeneous variation of 11.125 years, this period seemed almost entirely absent between 1749 and 1826. Its place was during that interval taken by two important groups of periodicities, one of which had a periodic time of about 9.25 years, while the second had an average period of 13.75 years. The latter period was represented more nearly by what in spectroscopy is called a "band" extending from 13.25 to 14.25 years, but some of this want of definiteness may be due to the deficiency in observational data. For some time I was inclined to draw the conclusion that such periodicities as we observe are comparatively short-lived, and replaced by a number of others, which in their turn die out. A more detailed investigation, however, convinced me that the periodicities are, as regards the interval of time elapsing between successive maxima, extremely regular, occurring with what may prove to be astronomical accuracy. The key of the solution is, I believe, to be found in the overlapping of a number of periods, all of which are regular as regards time, but vary considerably as regards intensity, so that one or other may for a certain number of years become inactive. Their real existence is proved by the fact that whenever they reappear after a period of inactivity, the phase of the renewed periodic action fits in exactly with the continuation of the old period.

I have approached the questions without preconceived opinions, and my first impression, as already stated, tended toward a denial

of fixed periods extending over long ranges of time. It was while writing out my conclusions to this effect, in preparing for publication, that I felt the impossibility of explaining some of the facts brought out by the periodogram as due to accident only, and I was thus forced toward a conviction that the periodicities were real and perfectly definite. The proof of the statement—which if true, must profoundly affect the problems of solar physics—can not be given here in its entirety, but I may briefly state the character of the evidence which to me was convincing.

A periodicity of about 4.78 years runs through the whole of the observations. Its amplitude, being about one-sixth of that of the eleven-year period, is too great to be accounted for by accident. It appears separately in the series of Wolf's numbers, ranging from 1749 to 1826 and from 1826 to 1900. It also appears in the series depending on the measurement of areas. The phases of the period as determined from these series are in good agreement, and even while I was inclined to question the permanency of the eleven-year period, I never felt any doubt that during the whole length of 150 years this period has been acting. Its time, determined as accurately as possible from the combined records, was 4.81 years, but I believe that, if greater weight were given to the more recent and more complete observations, the number would be slightly reduced. I wavered a long time between 4.78 and 4.81, and cannot distinguish with certainty between them. As regards the main period, which has certainly given its character to the sun-spot statistics during the greater part of the last century, I find the period, as determined from the observations since 1826 alone, to be 11.125 years. This agrees well with Wolfer's estimate of 11.124, and Newcomb's investigation, which led to 11.13 as the most probable number.

If to the most accurate series of measurements of sun-spot areas, which begin in 1832, we apply a process the result of which is the elimination of the chief period, and draw a curve representing what is left, we find decided maxima during the years 1836, 1845, 1853, 1862, and 1870; the intervals being alternatively 9 and 8 years, or 8.5 years on the average. The periodogram based on Wolf's numbers for the complete interval 1749–1900 shows a decided maximum

of intensity for a periodicity of 8.25 years. Adopting this period provisionally, and disregarding all observations since 1826, we may use Wolf's series previous to that date for the determination of the phase of the period in question, and thus forecast the maxima for the subsequent interval. We thus obtain 1836.3; 1844.7; 1852.9; 1861.2; 1869.4, in almost exact agreement wth the above. The slight error of phase would be corrected by assuming the time to have been 8.32 years.

A period of about 13.5 years shows as a maximum of intensity in the periodogram for the complete interval. In connection with it the following facts seem remarkable. There are in Wolf's records three cases of successive maxima having an interval of between 13 and 14 years. They are: 1626.0–1639.5; 1816.4–1829.9; 1870.6–1883.9. Also the interval between 1639.5 and 1816.4 is thirteen times 13.61, and the interval between 1829.9 and 1870.6 is three times 13.57. Thus the maxima all fit in with a period of about 13.6 years, which, with varying intensity, seems to have run through the whole record of observations.

Not wishing to lay too great a stress on what may prove to be merely a numerical coincidence, I return to the three periods which have been determined with some accuracy. It was only after the periodic times had been independently determined that the following remarkable relationship between the numbers was discovered. Taking frequencies into consideration, we are led to form the reciprocals of the periodic times and thus find:

$$\begin{array}{lcc} & \dfrac{1}{11.125} & = 0.08989 \\ & \dfrac{1}{8.32} & = 0.12019 \\ \hline \text{Adding up we find} & \dfrac{1}{4.76} & = 0.21008 \end{array}$$

Hence the sum of the frequencies of two of the periods agrees within the possible errors with the frequency of the third period. But it is also found that the first two numbers are very nearly in the ratio of three to four, so that we may also express the three periodic times as subperiods of 33.375 years. Thus:

$$\begin{aligned} \tfrac{1}{3} \times 33.375 &= 11.125 \\ \tfrac{1}{4} \times 33.375 &= 8.344 \\ \tfrac{1}{7} \times 33.375 &= 4.768 \end{aligned}$$

How far this connection is accurate or approximate is impossible to say at present, but the fact that the three periods which have been traced with a considerable degree of certainty should also bear a remarkable simple relationship to each other is worthy of note.

If we accept a period twice as long as that given above, we might account for some other periodicities of which at present the times are only approximately determined; thus $\frac{1}{5}\times 66.75$ would lead us to 13.34, in fair agreement with the period of 13.57 years which has been mentioned above. But the difference is greater than it should be, and at the present I do not wish to put forward the longer period as probable.

I wish, in conclusion, with all due reserve, to allude briefly to the more speculative side of the question. Though we justly keep the statistical problem distinct from theoretical considerations, yet a discussion of the possible causes which produce the periodicity of sun-spots may assist further investigations by suggesting definite problems. We must only take care that the statistics themselves are not affected, as is too often the case, by a theoretical bias which destroys their value.

The first question which occurs relates to the location of the origin of the periodical effect. Is it internal or external to the solar surface? At present this question can be answered only by an indefinite and instinctive feeling as to the relative probability of the two rival hypotheses. I have consistently advocated the external origin, chiefly because orbital revolution was the simplest solution of periodic effects having the length of period shown by the sun-spot activity. As far back as 1878[1] I suggested a meteoric origin of the sun-spot cycle, and pointed out the changes in the shape of the corona which run parallel with that cycle. In a paper[2] which for the first time proved the possibility of ionizing a gas by means of the electric discharge, I drew attention to the importance of this discovery in explaining such phenomena as the diurnal variation of terrestrial magnetism. In a lecture delivered before the Royal Institution[3] I supported the idea of an electric origin of the luminosity of the corona which had been previously put forward by Sir

[1] *Observatory*, 2, 262. [2] *Proc. R. S.*, 42, 371, 1887.

[3] *Proceedings of the Royal Institution*, 1891.

William Huggins, and gave reasons for believing that the substance of the corona is partly formed by matter thrown out from the body of the Sun. I specially pointed out the similarity of the shape of the corona at a time of minimum sun-spots to a kathode acting in a magnetic field.

In my introductory address before the Mathematical and Physical section of the British Association,[1] I asked the question:

> May not the periodicity of sun-spots and the connection between two such dissimilar phenomena as spots on the Sun and magnetic disturbances on the Earth be due to a periodically recurring increase in the electric conductivity of the parts of space surrounding the Sun? Such an increase might be produced by meteoric matter circulating around the Sun.

The experimental progress made since then has added enormously to our knowledge regarding ionization, and the electric origin of the coronal streamers is now, I believe, universally accepted. In addition to the electric effects, we have learned to take account of the repulsion due to radiation which was first applied by Fitzgerald to the explanation of comets' tails, and has recently been brought into the discussion of solar effects, by Arrhenius and others. The general idea seems to be that the Sun is discharging negative electricity, and therefore its own positive charge must be accumulating. This charge itself will be dissipated because nothing can keep it on the surface of a body as hot as the Sun, but its dissipation may be very much slower than that of the negative charge. We have here conditions which might set up secondary discharges in the electric field formed by the projected negative matter and the positive charge left behind. These discharges would, according to this hypothesis, cause the luminosity of the corona, in so far as this is not due to self-luminous solid or liquid matter or to scattered light. But the electric disturbances in the field surrounding the Sun must, as regards intensity, be variable according to the amount of existing ionization, and this ionization will be affected by the circulation of meteoric matter.

This brings us to a possible explanation of the periodic effects. Imagine a meteoric stream passing at perihelion within a few solar diameters from the Sun. If this stream in its circulation has picked

[1] *British Association Reports*, 1892, 367.

up, as probably it would, some of the negative ions which had previously been projected outward by the Sun, it would at perihelion affect the luminosity and shape of the corona, and would generally increase the electric conductivity in the neighborhood of the Sun. A meteoric stream having an orbital revolution of 11.125 years might cause effects which are periodic in that time. The manner in which the spot phemonena may be secondary effects of the coronal disturbances, which I consider to be the primary effect, need not be discussed here. In addition to the suggested fertilization by ions projected from the Sun and brought back by the meteor stream, even more powerful causes might be supposed to act, if, during the journey of the solar system through space these streams were to pick up radio-active matter which we may imagine to be distributed throughout space. The possibility that one and the same stream might be effective during three or four successive revolutions and then become sterile owing to its passage through a portion of space void of ionizing constituents would give a simple explanation of the variability in its activity. If the sun-spot changes could be represented by the superposition of a few detached periodic effects, we should be led to the consideration of several active meteor streams. The possible existence of more than one stream will probably not be denied by anybody. There is, however, a difficulty to be found in the numerical relationship between the periodic times. If we imagine that the periodic time of the hypothetical stream is 33.375 years, a time which I am told by Professor Turner is very nearly equal to that of the Leonids, we should have to conclude that the meteoric matter is to a great extent concentrated at three points, reaching perihelion at equal intervals. The 8.32 period would have to be accounted for by concentrations at four equidistant points, one of which would have to be coincident with one of the three belonging to the other system. Questions of stability could probably be made to account for a concentration of matter at regular intervals in the orbit, but the superposition of two or more systems seems to me to present great difficulties. The first of the relationships which has been pointed out may, however, be due to some cause analogous to the one which in sound produces combination tones. If there are two periodic causes, which we may represent by cos n_1t and cos n_2t, producing

effects which are not simply proportional to the cause, but partly also to the squares and higher powers, the effects will have a term depending on

$$(\cos n_1t+\cos n_2t)^2=1+\tfrac{1}{2}\cos 2n_1t+\tfrac{1}{2}\cos 2n_2t+\cos(n_1+n_2)t+\cos(n_1-n_2)t.$$

If $\cos n_1t$ and $\cos n_2t$ represent the eleven-year and eight-year period respectively, $\cos(n_1+n_2)t$ would represent a 4.78-year period and $\cos(n_1-n_2)t$ a period of $33\frac{3}{8}$ years. The latter period has often been put forward as suggested by the observations, though I cannot detect any observational evidence for it beyond the fact that the two sun-spot maxima in 1837 and 1870 were stronger than those immediately preceding or following. On the whole, the harmonic ratios formed between the numbers representing the periodic times of the three best-established sun-spot cycles seem to be a difficulty in the hypothetical explanation here put forward.

ULTRA-VIOLET ABSORPTION SPECTRA IN RELATION TO PHYSICO-CHEMICAL PROCESSES

By E. C. C. BALY AND C. H. DESCH

The fact that certain organic compounds exhibit banded absorption in the ultra-violet region of the spectrum was discovered by Hartley and Huntington in 1879.[1] The number of compounds submitted to examination since that time is very large, interest having been aroused in the subject from the fact that the nature of the absorption was soon found to bear an intimate relation to the chemical character of the compound. When this result was once established, the method was frequently and successfully employed to determine the constitution in doubtful cases.

Hartley and Huntington's method, which is still in use, consists in photographing a spark spectrum by means of a quartz spectrograph, after passing through a layer of a solution of the substance under examination. These authors found water and methyl and ethyl alcohols to be highly diactinic, transmitting all the rays as far as $\lambda = 2000$ Å. U. It is therefore possible to employ them as solvents for the organic compounds to be investigated. As source of light the spark spectrum of an alloy of tin, lead, cadmium, and bismuth is employed. This spectrum contains a considerable number of lines fairly equally distributed over the blue and ultra-violet regions, and it is therefore easy to detect the presence of absorption, and to measure its limits by observing whether any lines or groups of lines are missing.

In studying questions of constitution, it is not sufficient to determine the position of the absorption band in any given case; it is also required to know the way in which the selective absorption varies with changes in the concentration of the solution. For this purpose a series of photographs of the spark spectrum is taken through layers of varying thickness of the solution, the process being continued until complete transmission is obtained. The

[1] *Phil. Trans.*, 170, 257, 1879; *Proc. R. S.*, 31, 1, 1880.

results are expressed graphically in the form of a curve, the oscillation-frequencies of the limits of absorption being plotted against the concentrations, and the curve drawn through the points so obtained. It is the form of these curves, called by Hartley curves of molecular vibrations, which is of importance in relation to the chemical constitution.

It has been found that there are, broadly speaking, two types of ultra-violet absorption spectra, one in which the absorption is perfectly general, all rays above a certain oscillation-frequency being absorbed, the other selective, showing one or more distinct absorption bands. The majority of the aliphatic compounds belong to the first class, while aromatic compounds generally exhibit selective absorption. In both cases, however, there are exceptions to the general rule, some of which are considered in the present paper.[1]

We have been led to consider the meaning of the ultra-violet absorption spectra by some investigations which we have recently carried out on aliphatic compounds exhibiting tautomerism, of which acetylacetone and ethyl aceto-acetate are the types.[2] Although containing only open carbon chains, these compounds show marked banded absorption in solution. Their study presents a special interest from the fact that it is possible to investigate the bands without the complications introduced by the presence of an aromatic nucleus.

We have adopted Hartley's method of work, with certain modifications. In place of the electric spark between electrodes of an alloy as a source of illumination, we have employed an arc between iron poles. This reduces the length of exposure considerably when photographing the spectra, and from the great richness in lines of the iron arc spectrum the accurate determination of the limits of absorption is greatly facilitated. An adjustable cell has been used to contain the absorbing solutions. This consists of two glass tubes, one of which fits loosely into the other. Both tubes have a flange at one end, which is ground flat and at right angles to the axis, and on each flange a quartz plate is cemented. A broad

[1] For a summary of the results obtained by various workers with ultra-violet absorption spectra, see *Brit. Assoc. Rep.*, 1901, 225; and Kayser, *Handbuch der Spectroscopie*, Leipzig, 1905, Vol. III, Chap. 3 (compiled by Professor Hartley).

[2] *Chem. Soc. Journ.*, **85**, 1029, 1904.

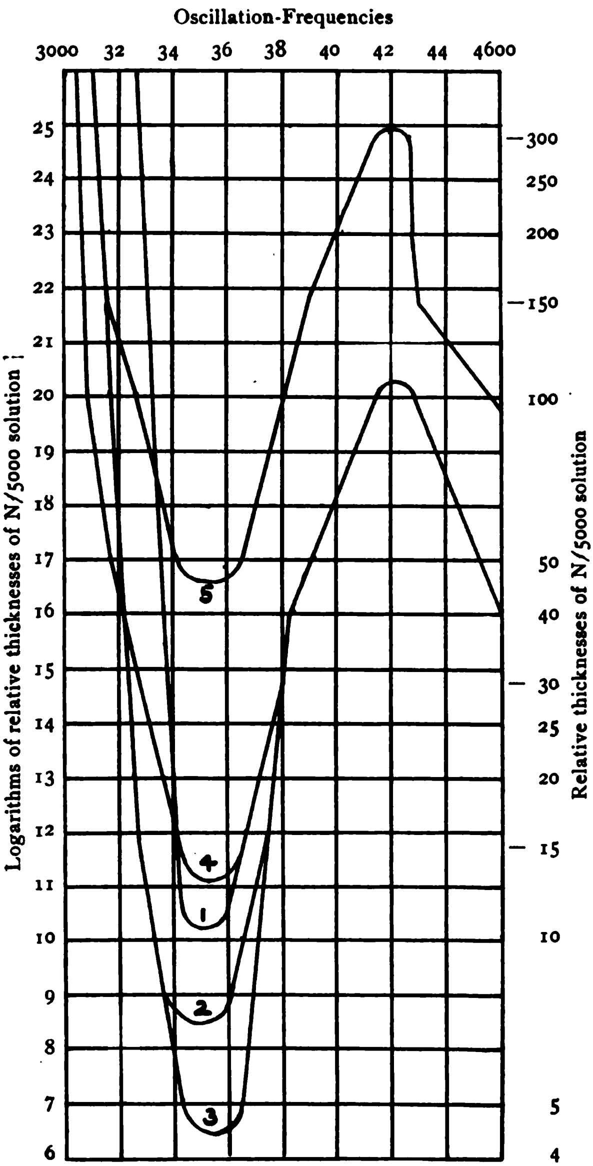

FIG. 1

Curve 1. Acetylacetone.
2. *Be* derivative.
3. *Al* derivative.
4. *Th* derivative.
5. Methylacetyl acetone.

india rubber band is slipped over the open end of the outer tube, and through this the inner tube slides freely, making a water-tight joint. A bulb-tube sealed on to the outer tube serves to take up the excess of solution as the inner tube is pushed inward, and a millimeter scale etched on the glass enables the thickness of the layer of solution to be read off directly. The use of such an adjustable cell is obviously more convenient than that of a number of cells of fixed thickness.

In actual practice, one tenth of a milligram-equivalent of the substance is dissolved in 50 cu. cm of the solvent—usually absolute alcohol, but in certain cases distilled water. The solution is put

into the absorption cell, and the iron spectrum is then photographed successively through 35, 30, 25, 20, 17, 15, 12, 10, 8, 6, 5, and 4 mm layers, and if necessary the same thicknesses are again employed after diluting the solution to ten times the original volume. It is found that the whole absorption band can, as a rule, be traced by examining in this way solutions of one five-hundredth and one five-thousandth normal concentration. In this way a complete record of the absorption is obtained over a range of from 4 to 350 mm thickness of a five-thousandth normal solution.

We have employed a new method of exhibiting the results graphically. The oscillation-frequencies of the limits of transmission are, as usual, taken as abscissæ, but instead of the concentrations or thicknesses of solution, the *logarithms* of the thickness are plotted as ordinates. This method has the great advantage that a given relative change of concentration is represented by the same change of ordinates in any part of the diagram; so that an absorption band which, for example, just persists while the concentration is halved, occupies the same space when plotted, whatever the absolute concentration may be. This persistence is a very characteristic function of a band, and has great theoretical importance.

The first compounds which we investigated were acetylacetone $CH_3-CO-CH_2-CO-CH_3$ and ethyl aceto-acetate, $CH_3-CO-CH_2-CO_2Et$, and their respective metallic derivatives. Acetylacetone itself, and its beryllium, aluminium, and thorium derivatives, were found to give very similar spectra, although differing somewhat in the breadth and persistence of the absorption band (Fig. 1). On the other hand, ethyl aceto-acetate gave only a slight general absorption without any trace of a band, while its aluminium derivative gave a banded spectrum almost identical with that of acetylacetone. This seemed to accord with the view that the band is due to the enolic grouping $-CH:C(OH)-$, since the results of Perkin,[1] Brühl,[2] and Drude[3] have made it probable that free acetylacetone has the enolic, and ethyl aceto-acetate the ketonic, structure. The metallic derivatives must then have the enolic structure, the metal being attached to the oxygen atom.

[1] *Chem. Soc. Journ.*, **61**, 800, 1892.

[2] *Ber.*, **27**, 2378, 1894. [3] *Ibid.*, **30**, 940, 1897.

Further consideration showed, however, that this explanation could not be considered satisfactory. There is no *a priori* reason why an enolic compound should exert banded absorption, since no band is produced by the presence of a double bond or of a hydroxyl group. Neither the ketonic $-CH_2-\overset{C}{\underset{O}{\|}}-$ nor the enolic $-CH=\overset{C-}{\underset{OH}{|}}-$ grouping should therefore give rise to a band. In order to test this point we examined the $O-$ and $C-$ ethyl derivatives of ethyl aceto-acetate, namely ethyl $\beta-$ ethoxycrotonate $CH_3-\overset{C}{\underset{OEt}{|}}=CH-CO_2Et$, and ethyl ethylacetoacetate $CH_3-\overset{C}{\underset{O}{\|}}\cdot CHEt-CO_2-CH_3$, and found that the enolic compound exerts only general absorption without any trace of a band, while the ketonic compound is practically completely diactinic. As it has been shown by Hartley and others that the replacement of a hydrogen atom by a light alkyl group does not modify the type of spectrum, these results leave no doubt that the spectra of the pure enolic and the pure ketonic modifications show no band. Further, no band is given by a mixture of the two isomeric ethyl derivatives. The purely ketonic acetonylacetone $CH_3\cdot CO\cdot CH_2\cdot CH_2\cdot CO\cdot CH_3$, and the purely enolic ethyl ethoxyfumarate, $CO_2Et\cdot C\ (OEt) : CH\cdot CO_2Et$, also show only general absorption without indication of a band.

It seemed probable therefore, that the absorption was not to be attributed to any definite molecular structure, but rather to the existence of dynamical isomerism between two modifications of the compound present in the solution. The evidence for the existence of isomerides in a state of dynamical equilibrium in solutions has recently been summarized by Lowry,[1] and it is now generally admitted that the chemical and physical properties of so-called "tautomeric" substances are best explained by the assumption of such dynamical isomerism. Our results seemed to justify the view that the absorption bands observed were connected with the intramolecular change from one modification to the other. In order to test this explanation, we have investigated the action of alkalis and of acids on the absorption spectra. It was found by Lapworth and Hann[2] that the final state

[1] *Brit. Assoc. Rep.*, 1904, 193. [2] *Chem. Soc. Journ.*, 81, 1508, 1902.

of equilibrium in the cases examined by them was independent of the presence of a catalytic agent; but that the velocity of transformation of one modification into the other, and therefore the rate at which equilibrium was reached, was in general accelerated by the presence of bases and retarded by that of acids. The final state being unaffected by the catalytic agent, this implies that the direct and reverse changes are equally accelerated or retarded. If, then, the absorption bands are due to an intramolecular change, the acceleration of this change by addition of a catalytic agent should show itself in the increased persistence of the band, and a retardation of the change by a diminution of the persistence. Experiment confirms these conclusions. The absorption of ethyl acetoacetate is shown in Fig. 2, curve 1; curve 7 being obtained on addition of

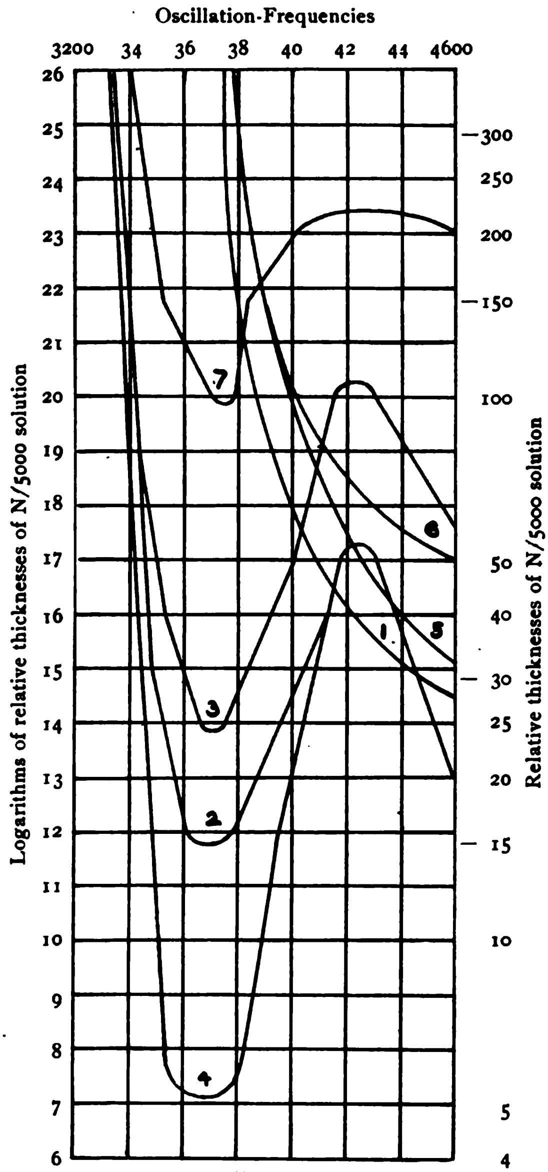

FIG. 2

0.5 equivaalent of sodium hydroxide, curve 3 with 1 equivalent, and curve 4 with an excess of the alkali. Curve 2 shows the absorption of the aluminium derivative. This figure indicates the value of the logarithmic method of plotting, for the persistence of the band is directly proportional to its height on the ordinates, and it will be noticed that this persistence increases with an increasing proportion of alkali. In the presence of an excess of sodium hydroxide, the band is more persistent than that given by the pure aluminium derivative, which is a striking fact in support of our views. The retarding action of hydrochloric acid is also shown in Fig. 2, curves 5 and 6 being obtained on the addition of a trace and of an excess of this acid respectively. These results indicate that ethyl acetoacetate is not entirely ketonic, but that there is an equilibrium with a small quantity of the enolic modification. This conclusion is also in accordance with the known physical and chemical properties of the ester.

A similar but even more marked retarding action of hydrochloric acid was observed in the case of ethyl β–aminocrotonate in which oscillation between the modifications $CH_3 \cdot \underset{NH_2}{\overset{C}{|}} : CH \cdot CO_2Et$ and $CH_3 \cdot \underset{NH}{\overset{C}{\|}} \cdot CH_2 \cdot CO_2Et$ is possible. In this case the persistence of the band is steadily diminished by successive additions of acid.

We have recently[1] extended this investigation by examining several other compounds, including ethyl acetylsuccinate, $CH_3 \cdot CO \cdot CH(CO_2Et) \cdot CH_2 \cdot CO_2Et$, ethyl diacetylsuccinate, $CH_3 \cdot CO \cdot CH(CO_2Et) \cdot CH(CO_2Et) \cdot CO \cdot CH_3$, ethyl benzoylacetate, $C_6H_5 \cdot CO \cdot CH_2 \cdot CO_2Et$, ethyl oxaloacetate, $CO_2Et \cdot CO \cdot CH_2 CO_2Et$, ethyl acetonedicarboxylate, $CO_2Et \cdot CH_2 \cdot CO \cdot CH_2 \cdot CO_2 Et$, ethyl benzoylsuccinate, $C_6H_5 \cdot CO \cdot CH(CO_2Et)CH_2 \cdot CO_2Et$, and benzoylacetone, $C_6H_5 \cdot CO \cdot CH_2 \cdot CO \cdot CH_3$, and certain of their metallic derivatives. (For the sake of brevity, only the ketonic formula is indicated in each case.) Of these, only three, namely, benzoylacetone, ethyl benzoylacetate, and ethyl benzoylsuccinate, exhibit absorption bands in the free state, but a band is in each case produced by the addition of sodium hydroxide.

[1] *Chem. Soc. Journ.*, 87, 766, 1905.

It will be seen on reference to Fig. 1 that the oscillation-frequencies of the absorption bands given by acetylacetone and its metallic derivatives are almost identical. We have obtained similar results in our more recent work, and we find generally that the band of the metallic derivative is usually shifted slightly toward the red as compared with the free substance, but that the amount of shifting is not the same in all the compounds examined, nor does it bear a simple relation to the mass of the metallic atom replacing hydrogen. It is rather such as might be expected from the small increase in the total mass of the molecule.

It is evident from a consideration of these results that some oscillation or free period must exist in connection with the reversible transformation of one tautomeric form into the other, which is synchronous with the oscillation of the light rays absorbed. It is not possible that this vibration can be the vibration of the labile atom itself, for, apart from the fact that the oscillation-frequency of the absorption band is found to stand in no direct relation to the mass of this labile atom, it is also noteworthy that the frequency is far greater than that usually attributed to atomic motions. We are therefore forced to conclude that the absorption of light is due to the transformation which is expressed chemically by a change of linking. In the case of the keto-enol tautomerides under consideration, this change is expressed by the equation:

$$-CH{=}\underset{\displaystyle OH}{\underset{|}{C}}- \leftrightarrows -CH_2-\underset{\displaystyle O}{\underset{\|}{C}}- \, .$$

We may represent this more simply as being due to the existence of a transitional phase:

$$-\overset{*}{CH}-\underset{\displaystyle O*}{\underset{|}{\overset{*}{C}}}-$$

in which the asterisks indicate that the atoms so marked are actually in the state of changing their linking.

In seeking to form a physical conception of the process involved, several facts, derived from the results of previous workers in this field, have to be taken into consideration. A study of the data obtained by Hartley and others, and summarized in Professor

Kayser's *Handbook*, Vol. III, Chap. 3, shows that an absorption band in the ultra-violet region of the spectrum is only shown by compounds having a possibility of tautomerism. Such tautomerism is not necessarily due to the presence of a labile atom, but may be of the same order as that occurring in ring compounds of the aromatic type, in which a reversible change of linking may take place periodically. The absorption bands of all the simpler tautomeric molecules, that is to say, in which open chains only are concerned in the change of linking, have approximately the same frequency. An increase in the mass of the molecule causes a decrease in the oscillation-frequency of the band, which is consequently displaced toward the red end of the spectrum; but this displacement is only a small fraction of the whole frequency, and the approximate constancy of the position of the band throughout this large class of compounds points strongly to the existence of some condition common to the whole group, to which the absorption is to be ascribed. Further, Hewitt has shown[1] the intimate relation existing between tautomerism or dynamic isomerism and fluorescence, from which it appears that compounds undergoing labile change of this type are in certain cases capable of selecting certain radiations and of emitting them at a different frequency. The experiments of Armstrong and Lowry[2] also indicate that dynamic change may even be accompanied by the emission of visible radiations, in the phenomena of triboluminescence.

No explanation has yet been brought forward of the whole of these facts. In order to obtain such an explanation we believe it to be necessary to examine the phenomena, not merely from the chemical, but also from the physical point of view. The facts connected with the nature of emission spectra, the grouping of spectral lines into series, the action of a magnetic field on radiation (the Zeeman effect) and the phenomena of radioactivity, are all co-ordinated by means of the hypothesis which regards the chemical atom as a system of electrons. On this hypothesis, the atom is considered to be a system of extremely small particles carrying a negative electrical charge, revolving in orbits about a common center of attraction. One form of this hypothesis, which appears to have

[1] *Zeit. physical. Chem.*, 24, 1, 1897. [2] *Proc. R. S.*, 72, 258, 1903.

special advantages from the spectroscopic point of view, regards the system as being exactly comparable with that of the planet *Saturn*, electrical being substituted for gravitational attraction. That is to say, the small, negatively charged electrons are considered to revolve in a belt about a larger, positively charged central body.[1] The phenomena of radiation are well explained by the regular or disturbed motions of such a system. The arrangement assumed by J. J. Thomson is somewhat similar.

On such a hypothesis, chemical combination between two atoms results in the transference of one or more electrons from one atom to another. One or more Faraday tubes of force are thus produced between the two atoms, each tube representing the chemist's single bond of affinity. If by any means a rearrangement of the Faraday tubes is brought about, a vibrational disturbance is set up in the electron systems. The change of linking between different atoms involved in tautomeric or isodynamic change implies the repeated making and breaking of Faraday tubes, owing to the transference of electrons from one atom to another. If Hewitt's explanation of the origin of fluoresence be accepted, it follows that the vibrational disturbances thus set up by isodynamic change are of the same order of frequency as light-waves. In accordance with the principle of resonance, therefore, a system in which such vibrations are going on will absorb light rays of that period. Since the vibrations will not be synchronous, the absorption band thus produced will have an appreciable breadth.

By means of this hypothesis, the phenomena of absorption are brought into the same category as those of radiation. In the case of luminosity produced by heat or by electric action, the origin of the luminosity lies in the rapid changes of stress or electric field to which the molecules or atoms are subjected. In the case of absorption by tautomeric substances, the disturbances of the electrons are due to changes of linking within the molecule. The presence of a labile atom is not necessary, as the alternating changes of linking in a ring of atoms of the benzenoid type gives rise to absorption of the same kind.[2] The comparatively small displacement of the absorp-

[1] Nagaoka, *Nature*, **69**, 392, 1904.

[2] For an experimental study of this case, see Baly and Collie, *Chem. Soc. Journ.*, **87**, 1332, 1905; Baly and Ewbank, *ibid.*, 1347, 1355.

tion band by an alteration of the mass of the molecule is in accordance with our view. An increase in the mass of matter in the immediate neighborhood of the vibrating electrons has the effect of retarding their motions, the oscillation-frequency thus becoming less. This is well shown in the case of the emission spectra of the elements. Closely related chemical elements show spectra of similar structure, but the spectral series show a displacement toward the red, that is, a decrease of frequency, with increasing atomic mass. For example, the first members of the principal series of the alkali metals are represented by the following equations of Kayser and Runge, n being the oscillation-frequency and m the number of the line in the series (3, 4, 5, etc.):

$$\text{Lithium,} \quad n=43584.75-\frac{133669}{m^2}-\frac{1100084}{m^4}\ ;$$

$$\text{Sodium,} \quad n=41542.51-\frac{130233}{m^2}-\frac{800791}{m^4}\ ;$$

$$\text{Potassium,} \quad n=35086.55-\frac{126983}{m^2}-\frac{625318}{m^4}\ ;$$

$$\text{Rubidium,} \quad n=33762.11-\frac{125531}{m^2}-\frac{562255}{m^4}\ ;$$

$$\text{Cæsium,} \quad n=31509.31-\frac{125395}{m^2}-\frac{486773}{m^4}\ .$$

The first term of the above equations, or the value of the oscillation-frequency when $m=\infty$, called the convergence frequency, is seen to decrease with increasing atomic weight. This is generally true of emission spectra. Similar relations have been observed in absorption spectra in the visible region, as in the case of didymium salts, the absorption bands of which were shown by Bunsen[1] to be displaced toward the red with increasing molecular weight. A similar displacement is well known in the case of organic dyes, which become increasingly blue in color as heavy groups are introduced into the molecule; that is to say, the absorption bands are displaced toward the red end of the spectrum.

The bearing of the facts just described on the theory of solutions may next be considered. We have shown that solutions of both the sodium and the aluminium derivatives of ethyl acetoacetate contain

[1] *Pogg. Ann.*, **128**, 100, 1866.

the enolic and ketonic modifications in dynamical equilibrium; that is the metallic atom is alternately linked to the carbon and to the oxygen atom. But from the chemical point of view there is an important difference between the two derivatives. The sodium compound is readily ionized, and in dilute solutions is almost completely hydrolysed into sodium hydroxide and free ethyl acetoacetate. The aluminium derivative, on the other hand, undergoes dissociation and hydrolysis only to a very small extent.[1] The absorption spectrum is not therefore dependent on either ionization or hydrolysis. In this connection the work of Hartley on the ultra-violet absorption spectra of metallic nitrates[2] is of great importance. Hartley showed that the metallic nitrates exhibit an absorption band in dilute aqueous solution, and that the position of this band depends on the mass of the metal. This is the case even in solutions which on the ordinary hypothesis are almost completely dissociated, as shown by their electrical conductivity. There is therefore direct evidence of a physical connection between the anion and cation in such solutions. Even without the evidence furnished by Hartley's results, the difficulty felt in forming any distinct physical conception of a solution in which the ions have an entirely independent existence points to the same conclusion. The physical objections to the hypothesis of independent ions have been clearly stated by Fitzgerald in his Faraday lecture.[3] A theory of solution must therefore take into account the persistence of a physical connection between the ions, even in the most dilute solutions.

To take the simplest case, that of a binary salt dissolved in water, the two atoms composing the salt are connected by means of a Faraday tube of force, as stated above. On bringing the system into the presence of a large number of molecules of water, as in the process of dissolution, the atoms are drawn apart, and the Faraday tube between them is correspondingly lengthened, without, however, being broken. The force needed to separate the atoms, or ions as they may conveniently be called, is furnished by the attraction of the solvent.

[1] Hantzsch and Desch, *Ann.*, **323**, 1, 1902.

[2] *Chem. Soc. Journ.*, **81**, 571, 1902; **83**, 221, 1903.

[3] *Ibid.*, **69**, 885, 1896.

The solvents which produce this effect, the so-called "ionizing solvents," are those possessing marked residual affinity, such as water, alcohol, liquid sulphur dioxide, and ammonia. That the chemical affinity of the solvent for the dissolved substance plays an important part in the phenomena of solution is becoming increasingly obvious, whatever view may be taken of the way in which this affinity acts. But the attraction of the solvent is not merely exerted on the molecule as a whole, but also on its components separately. The conception of such an attraction of the solvent for the ions is involved in the use of the expression "hydrated ions."[1] An ionizing solvent is one the affinities of these for the dissolved molecule and its component ions are such as to bring about this separation of the atoms and lengthening of the Faraday tubes. When this lengthening reaches a certain critical value, an interchange of ions between molecules approaching one another in the solution becomes possible. We assume that no such interchange is possible so long as the Faraday tubes are in all cases below the critical length. The interchanges may be represented diagrammatically as taking place in the following way:

$$\begin{matrix} A & B \\ | & | \\ B & A \end{matrix} \qquad \begin{matrix} A\diagdown \\ \\ B\diagup \end{matrix}\Big)\Big(\begin{matrix} \diagup B \\ \\ \diagdown A \end{matrix} \qquad \begin{matrix} A-B \\ \\ B-A \end{matrix}$$

Transition phase

On this view, a "completely dissociated" dilute solution of a salt is not one in which the ions are moving about independently of one another, but is one in which the Faraday tubes have been lengthened sufficiently in the case of every molecule present to allow of free interchange. A "partially dissociated" solution is one in which a greater or less proportion of the Faraday tubes exceed the critical length, but not the whole. Physical properties such as the electrolytic conductivity and the osmotic pressure furnish a means of determining the proportion of molecules in this state.

In solutions of tautomeric substances we have the Faraday tubes or bonds connecting the labile atom with the rest of the molecule lengthened to such an extent as to allow of these atoms changing

[1] See, for a summary of this question, Walden, *Zeit. phys. Chem.*, **39**, 539, 1902; Baur, "Von den Hydraten in wässeriger Lösung," *Ahrens Sammlung*, 1903; Lowry, *Trans. Faraday Soc.*, **1**, 197, 1905.

from one position to another within the same molecule. We have then a kind of internal ionization, with the labile atom as a potential ion. The making and breaking of the Faraday tubes accompanying this change causes the oscillatory disturbances to which we have attributed the absorption bands. The lengthening of the tubes of force may be insufficient to allow of free interchange between different molecules, so that "ionization" as shown by electrical conductivity, etc., may be absent, as in the case of ethyl acetoacetate and its aluminium derivative, and many similar compounds. It is well known that in the case of the tautomeric aliphatic compounds the replacement of a labile hydrogen or metallic atom by an alkyl group destroys the tautomerism. This is entirely in accordance with the fact that alkyl ions are unknown. The attraction of water or alcohol appears to be insufficient to lengthen the Faraday tubes connecting alkyl or similar groups with the rest of the molecule to a sufficient extent to allow of either internal or intermolecular interchange. Even in such solutions as these the molecules must be regarded as in a state of strain, and it is probable that a very small increase of tension would suffice to lengthen the Faraday tubes beyond the critical value. Such an increase may conceivably be produced by the introduction of another substance into the solution. The resulting change of physical and chemical conditions may bring about the lengthening to such an extent that the critical value is overstepped and interchange takes place. This is a possible explanation of the numerous reactions between substances in solution, especially in organic chemistry, which appear to take place between ions, although the external evidences of ionization, such as the presence of electrolytic conductivity, are absent.[1] Several grades of this ionic separation must thus be considered to exist.

Firstly, there are solutions, such as that of mercuric cyanide in water, where the lengthening of the Faraday tubes is insufficient to allow of interchange; the salt is therefore spoken of as non-ionized.

The second grade is represented by the tautomeric compounds containing a labile atom, intramolecular interchange thus being possible. Thirdly, we have the condition existing in ordinary salt solutions, in which the interchange of ions takes place more or less

[1] See especially Kahlenberg, *Journ. Phys. Chem.*, **6**, 1, 1902.

freely. The group of complex salts may be considered as a subdivision of this class. A complex salt such as $KAg(CN)_2$ undergoes dissociation into K and $Ag(CN)_2$ ions; that is to say, interchange of these ions takes place freely. In addition to this, the solvent tends, especially in dilute solutions, to separate the components of the complex ion sufficiently to permit of interchange between them, so that we have evidence of the presence of Ag and CN ions in the solution. Viewed in this way, the differences between dissociated and undissociated compounds in solution become differences of degree and not of kind. There is no discontinuity in the action of the solvent, which always tends to separate the ions, thus lengthening the tubes of force between them.

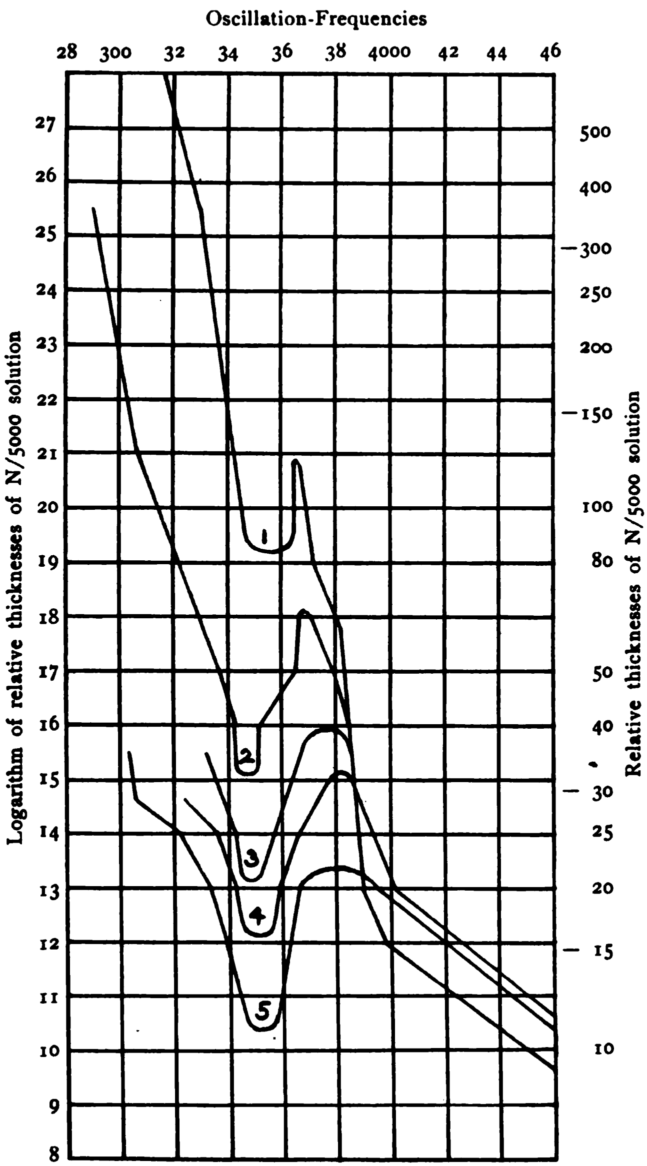

FIG. 3

Whether this results in the formation of an electrolytically conducting solution, showing the ordinary properties of ionization, depends upon whether all or some of the tubes of force are extended beyond the critical length at which interchange becomes possible, or not.

One consequence of these views in the case of open chain tautomeric compounds can be put to the test experimentally. It has been said already that the persistence of the absorption bands given by these compounds is a measure of the number of molecules undergoing transformation at any moment. That is to say, it is a measure of the number of cases in which the labile atom is separated from the rest of the molecule by a distance exceeding the critical value. There should therefore exist for each tautomeric compound a maximum value of this persistence, corresponding with the lengthening of all the bonds beyond this critical value, so that free interchange is taking place. Now, it was shown above that the addition of sodium hydroxide increases the persistence of the bands; that is to say, it favors the lengthening of the tubes of force, and consequently facilitates interchange. Successive additions of the accelerating reagent may therefore be expected to increase the persistence of the band until a maximum is reached. We have tested this conclusion in the case of ethyl benzoylsuccinate[1] observing the absorption spectrum of solutions of this compound alone and in the presence of 1, 10, 20, and 100 equivalents of sodium hydroxide. The limits of persistence observed are as follows:

	Free Ester	Ester with 1 Eq. *NaOH*	Ester with 10 Eq. *NaOH*	Ester with 20 Eq. *NaOH*	Ester with 100 Eq. *NaOH*
Absorption band begins at.....	120 mm	63 mm	40 mm	31.7 mm	21.9 mm
Absorption band ends at......	83.2 mm	34.7 mm	20 mm	15.2 mm	10.4 mm
Change of dilution over which the absorption band persists.	30.7%	44.9%	50%	52%	52.5%

The thicknesses given refer to a 1/10000 normal solution of the ester. The complete absorption curves are shown in Fig. 3, in which curve 1 is that of the free ester, and curves 2, 3, 4, and 5 are those of the ester in the presence of 1, 10, 20, and 100 equivalents

[1] *Chem. Soc. Jour.*, 87, 766, 1905.

of *NaOH* respectively. It will be seen that the maximum is practically reached on the addition of 20 equivalents, an increase of the alkali to 100 equivalents only bringing about an increase of persistence of 0.5 per cent.

CONCLUSIONS

The following conclusions may be drawn from the experiments described:

1. In the case of solutions of the aliphatic tautomeric substances neither the pure ketonic nor the pure enolic modification gives an absorption band in the ultra-violet region.

2. In solutions of the concentrations considered by us the pure ketonic modification is almost completely diactinic, while the pure enolic modification exerts a small general absorption.

3. An absorption band is obtained only when both modifications are present in a state of dynamical equilibrium with one another.

4. The persistence of the absorption band is a measure of the number of molecules in the changing state at a given time. It is probable that the number changing must be considerable in order to produce sensible absorption.

5. In the cases examined the persistence is increased by the addition of alkali hydroxide and diminished by the addition of acid.

6. Successive additions of alkali increase the persistence until a maximum value is reached, beyond which further additions produce no further effect.

7. These results are independent of the ionization or hydrolysis of the compounds examined.

8. The oscillation frequency of the absorption band varies slightly with the total mass of the molecule, but is not directly dependent on the mass of the labile atom.

9. The absorption band is due to the change of linking accompanying the reversible change from one tautomeric modification to the other, and its production may be explained by means of the conception of the atom as a system of electrons.

10. The change of linking may be due either to the motions of a labile atom or to the internal changes in a benzenoid ring, the same type of absorption band being produced in both cases.

11. The action of the solvent may be regarded as tending to lengthen the bond of attraction or Faraday tube of force between the atoms, until, when a certain critical length is reached, interchange of atoms from one position to another within the molecule becomes possible. Catalytic agents act by lengthening or shortening the tubes of force.

12. In the case of "ionized" solutions the lengthening of the tubes of force exceeds a value at which interchange between different molecules becomes possible. The "degree of ionization" is a measure of the number of interchanges taking place. When the length of the bonds is below the critical value, there is no evidence of ionization, but the critical length may be so nearly approached that a small external influence will cause it to be exceeded.

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PRELIMINARY RESULTS OF UNITED STATES NAVAL OBSERVATORY ECLIPSE EXPEDITION IN 1905

By COLBY M. CHESTER

The U. S. Naval Observatory expedition to observe the total solar eclipse of August 30, 1905, was sent out in connection with a squadron of three vessels detailed by the Navy Department, with the superintendent of the Observatory, Rear-Admiral C. M. Chester, U. S. N., as commander-in-chief. Three principal stations were established: one near the central line at Daroca, on the highlands of the Spanish peninsula, at an altitude of about 2500 feet; one near the southern edge at Porta Coeli, a few miles from the Mediterranean coast of Spain, at an altitude of about 1000 feet; and one near the central line at Guelma, Algeria, about 40 miles from the coast, at an elevation of about 1500 feet. At Daroca Professor of Mathematics W. S. Eichelberger was in charge. At Porta Coeli Professor of Mathematics F. B. Littell was in charge of the installation, to be relieved by Lieutenant-Commander E. E. Hayden when the whole party of observers was assembled. Rear-Admiral Chester took station here during the eclipse. At Guelma Captain J. A. Norris was in charge.

When it was decided to equip three stations completely for photographing the corona with long- and short-focus cameras, and for spectroscopic work, it was found that it would be necessary to supplement and remodel the available apparatus on hand to a considerable extent. A new 7½-inch lens of 65 feet focal length was made by Brashear. Two new cœlostats, designed by Mr. Dinwiddie, were made by William Gaertner & Co., of Chicago. The rest of the new apparatus required was constructed at the Observatory under the direction of Mr. Dinwiddie. Three polar axes were made 10 feet long, of steel and iron construction, so arranged that the cameras were hung within the frame. The tubes of the cameras to be used on the polar axes consisted of similar latticed iron framework lined with black velvet and covered with sheeting soaked in a mixture of linseed oil and lampblack. One new grating-holder was made, supporting the grating

from both sides of the camera frame, which was also of steel construction. Three portable dark-rooms for developing were constructed; also three portable dark-rooms for the long-focus cameras, and three tubes similar to the one used by Professor Barnard in Sumatra in 1901, but with ventilating doors on the under sides to be left open until a few minutes before totality.

Each station was equipped for the determination of latitude and longitude. At the two Spanish stations time signals were received from the Madrid Observatory over special wires kindly erected by the Spanish government, and at the African station signals were received from the Algiers Observatory. The latitudes were determined by Talcott's method.

Each station was supplied with one of the long-focus cameras mounted horizontally, the one at Porta Coeli having the new lens of 65 feet focal length, the other two stations having lenses of 40 feet focal length. There was also at each station one of the polar axes for carrying one or two cameras for obtaining coronal extension, together with spectroscopic and polariscopic apparatus.

Several parties of sailors, in charge of officers from the naval vessels, made drawings of the corona and shadow-band observations. One of these parties, in charge of the commanding officer of that ship, Captain J. M. Miller, U. S. N., was located on board the U. S. F. S. "Minneapolis," near the central line off the east coast of Spain; another under the charge of Commander G. A. Merriam, U. S. N., was located on board the U. S. S. "Dixie" near Bona, Algeria.

At each station a complete meteorological equipment was set up, and provision was also made for magnetic and photometric observations.

At none of the stations was there any interference from clouds, and the programs were carried out as planned.

The contacts were observed at all the stations, and were noted about twenty seconds ahead of the predicted time.

CORONAL PHOTOGRAPHS

Thirty-six photographs of the corona were taken at the three stations. At Daroca Mr. L. G. Hoxton obtained seven with the 40-foot camera, the exposure times being $\frac{1}{2}^s$, 2^s, 5^s, 45^s, 120^s, 5^s, and snap-shot; Paymaster H. R. Insley, U. S. N., obtained three with the

12-foot camera, of 5^s, 70^s, and 10^s exposure; and Midshipman E. W. Chafee, U. S. N., obtained three with the 36-inch Dallmeyer camera and color-screen, of 5^s, 70^s, and 40^s exposure. The drawing of the corona, Plate IX, was made from a study of the Daroca negatives.

At Porta Coeli Mr. G. H. Peters obtained seven negatives with the 65-foot camera, of 2^s, 3^s, 35^s, 5^s, 15^s, 3^s, and 2^s exposure, and four were obtained by Mr. G. A. Hill, with the 104-inch camera of 5^s, 10^s, 40^s, and 20^s exposure.

At Guelma Mr. W. W. Dinwiddie secured eight negatives with the 40-foot camera, the exposure times being 2^s, 5^s, 13^s, 88^s, 38^s, 7^s, 5^s, and $\frac{1}{4}^s$ ten seconds after the third contact; and Yeoman F. A. Achen four with the 15-foot camera, of 30^s, 55^s, 90^s, and 10^s exposure.

Both the early and late photographs with the long-focus cameras show numerous prominences, and the longer exposures show a great amount of intricate detail in the corona. The shorter-focus cameras show the corona extending two or three diameters from the limb of the Moon. On the last negative with the 40-foot camera at Guelma, taken ten seconds after third contact, the entire ring of the corona is visible, and the prominences on the bright limb are shown in fine detail.

SPECTROSCOPIC OBSERVATIONS

All spectroscopic work at the central Spanish station was in charge of Dr. S. A. Mitchell.

The success attending the work at the eclipses of 1900 and 1901, when gratings were used, was such as to show that splendid results might be obtained at the eclipse of 1905 from these gratings. Accordingly, the spectroscopic program included primarily large-scale photographs of the "flash" spectrum and the coronal spectrum to be obtained in this way. As there was a question as to whether the concave grating or flat grating were the better, it was decided to use both. In addition to the two powerful gratings, a short-focus concave grating was to be used for the purpose of finding the changes in the bright lines of the Sun's spectrum, and, finally, two prismatic spectrographs for finding the intensity of the light of the corona in different parts of the spectrum. Thus five spectrographs were used, three grating and two prismatic. In detail the instruments were as follows:

1. *Parabolic grating.*—This grating was the property of the Rum-

PLATE IX

COMPOSITE DRAWING OF THE ECLIPSE AT DAROCA, SPAIN

From negatives made with the 40-foot and 12-foot cameras.
Drawn by Capt. H. W. Carpenter, U. S. M. C.

ford Committee, and was kindly loaned by Professor F. A. Saunders, of Syracuse University. It is a 4-inch grating, with 14,438 lines to the inch, and has a focal length of almost exactly 5 feet. The spectrum was exceedingly bright in the first order on one side, and the definition was splendid. At the eclipse it was used without a slit, so that the spectrograph consisted merely of grating and photographic plate. The instrument was placed horizontally, and light was fed to it by means of a "Transit of *Venus*" cœlostat which did not work perfectly. On the eclipse day this instrument was placed in the hands of Ensign A. G. Howe, U. S. N., of the "Minneapolis." Eleven plates were exposed, everything passed off without a hitch, and the developed plates show splendid detail and are exceedingly interesting. On account of the spectrum being brought to a focus on a curve, it was necessary to use celluloid films. These films, $1\frac{1}{4}\times 12$ inches, were of two different kinds, Lumière "Panchromatic C" and Seed "Orthochromatic." The dispersion of this instrument is about the same as the Bruce three-prism spectrograph of the Yerkes Observatory and the Mills spectrograph of the Lick Observatory. The distance from D_3 to H is almost exactly 7 inches, the total length of the spectrum being 9.5 inches, and the definition excellent throughout its whole length. The flash extends from D_3 to λ 3300 and shows a very great number of lines.

The spectrum taken near mid-totality shows some interesting coronal rings. The green coronium ring appears very plainly, and two rings in the extreme ultra violet are just as prominent on the photograph as the green ring. As the plate used has a photographic action which is just as intense in the ultra-violet as in the green, it would seem that the corona is very rich in ultra-violet rays. The following coronal lines are seen at approximately $\lambda\lambda$ 3381, 3388, 3455, 3643, 3984, 4228, 4565, 4618, and the coronium line at λ 5303.

2. *Flat grating.*—This grating belongs to the Naval Observatory, has 15,000 lines to the inch, and a ruled surface $3\frac{1}{2}\times 6$ inches. The lens used with it is a Clark 5-inch visual with a focal length of about 6 feet. This instrument was also placed horizontally, and was fed by a Gaertner cœlostat. The field of the spectrum was sufficiently near a plane to allow glass plates to be used. These plates, $1\frac{1}{2}\times 14$ inches, were also of two different kinds, Lumière "Panchromatic C"

and Cramer "Trichromatic." Twelve exposures altogether were made. This instrument was used on eclipse day by Dr. Mitchell, assisted by two sailors of the "Minneapolis." The results are not quite so good as those obtained with the parabolic grating as the extreme ultra-violet is not in focus. On these plates the distance from D_3 to H is 8 inches. In the flash spectrum lines can be seen beyond the D lines toward the red almost to C. This is the end of the spectrum most desired, and the focus is excellent from F to the extreme of the red. The green coronium ring also appears on the plates taken near mid-totality.

3. *Short-focus concave grating.*—This grating, kindly loaned by Professor S. P. Langley, secretary of the Smithsonian Institution, was used for the purpose of finding the changes in the bright lines just before and just after totality. It has a ruled surface of 4×6 inches, with 3610 lines to the inch, and a radius of curvature of 64 inches. In view of its small dispersion, the spectra were excessively bright. The second and third orders were to be photographed on the same plate, and a number of exposures were to be given in quick succession at second and third contacts, the times of exposures being recorded on the chronograph. At the time of the eclipse, however, the success of this instrument was greatly interfered with by totality beginning about 20 seconds before the calculated time, so that the exposures at second contact, which were to run on both sides of the "flash," were all inside totality; and, in addition to this, the chronograph pen failed to write. However, the plates promise some interesting results upon more careful study.

4. Two prismatic instruments of the same dispersion were used for the purpose of finding the intensity of the corona in different parts of the spectrum. This was to be done by photographing alongside the coronal spectrum comparison spectra of the Sun under ordinary conditions and at different exposures in such a way that photometric measures might be made. These instruments were used with slits, and each consisted of one prism with the necessary collimator and objective.

The four lenses used were kindly loaned by the C. P. Goerz Co., and the prisms and slits were obtained from the Naval Observatory and the Department of Physics of Columbia University. The result-

ing photographs show the coronal spectrum exceedingly weak, so that no photometric measures are possible.

The spectroscopic apparatus used at the station at Porta Coeli, Spain, consisted of a 6-inch concave grating having a radius of curvature of 21½ feet, and ruled with 15,000 lines to the inch, loaned to the expedition by the Johns Hopkins University.

This was arranged to be used with parallel light reflected from one of the mirrors of a cœlostat in the usual manner, the first order spectrum being employed. Two plate-holders were used, each holding three films 2×24 inches, Seed "Orthochromatic." The region of the spectrum covered was from λ 3000 to λ 6000 approximately.

The duration of totality at this station being about 106 seconds, the exposures were arranged as follows, time being counted from the moment of second contact: 1, 0 to 4 seconds; 2, 6 to 20 seconds; 3, 22 to 70 seconds; 4, 86 to 100 seconds; 5, 102 to 106 seconds; 6, exposed for perhaps ½ second as soon after third contact as possible.

From the exposure times it is evident that plates 1 and 5 were intended to get the flash spectrum at second and third contacts; plates 2 and 4 to get the upper chromospheric and inner coronal lines; while plate 3 with the long exposure was intended to get principally the coronal spectrum. Owing to the moderate height of the solar atmosphere covered up by the Moon at mid-totality as seen from this station, it follows that the highest chromospheric lines, such as H and K, etc., would appear to some extent on all the plates.

Professor Littell changed the plates, and Mr. Anderson worked the shutter and determined the time for beginning the first and ending the fifth exposures, by observing the Sun directly through a small objective-grating direct-vision spectroscope. The observation of the time of second contact agreed almost exactly with that given by Commander Hayden, who observed at the 5-inch equatorial, and gave the signals to "begin" and "stop" for the photographic cameras; while the observation of the time of third contact was about two seconds behind that of Commander Hayden, who called "stop" at the count of the 104th second.

The plates were developed the evening of August 30. They show

quite an amount of detail, but the definition in general is not so good as might be wished. This may be ascribed to two causes: imperfect focusing, and vibration of the instrument during exposure.

The flash-spectrum plates both show a great amount of detail; plate 5 showing much more, however, than plate 1, indicating that its exposure was more nearly correct than that of plate 1; the definition on this plate is also very good, so it is hoped to get a great deal from it. Plates 2 and 4 show the higher chromospheric lines well, but do not show any of the coronal rings, and very little if any continuous spectrum. Plate 3 shows the green coronal ring fairly well, and quite a considerable amount of continuous spectrum, but fails to show any of the other coronal rings distinctly enough to allow of measurement. It also shows quite a number of the so-called inner coronal lines. None of the plates shows any lines beyond λ 3300, and possibly nothing beyond λ 3400.

Two of the prominences show a displacement of the calcium and hydrogen lines indicating motion in the line of sight, as it is greater in case of calcium than of hydrogen, and also much greater on plate 2 than on any other.

The spectroscopic work at the African station was in charge of Mr. L. E. Jewell, and the following instruments were employed.

(1) A 6-inch concave grating of 10 feet radius and 15,000 lines to the inch, belonging to the Naval Observatory. This instrument was used as a direct grating and was mounted on the polar axis. Eight exposures were planned for this instrument: $\frac{1}{2}^s$ ten seconds before totality; 3^s beginning at second contact; 30^s, 55^s, 90^s, 10^s, $3^s\pm$ ending at third contact; and $\frac{1}{2}^s$ as soon as possible after the end of totality.

On developing the films it was found that the program as planned and practiced had not been correctly carried out. Due probably to second contact occurring about 20 seconds before the predicted time, the first two exposures were late and the first flash was missed. The longer exposures show the chromospheric lines not perfectly sharp, yet fairly so, and the coronal rings generally excellent. The exposure for the second flash was not ended promptly at third contact, and as a consequence the spectrum of the solar crescent was allowed to come out on it for a short time. It is a fairly good film, however. The first

and last exposures of half a second each show considerable shaking of the instrument, and the others in a less degree.

The green ring shows remarkably well upon three plates, fairly well upon two others, and is suspected upon a sixth.

The ultra-violet rings at λ 3382 and λ 3453 show well upon two films, fairly so upon a third, and are suspected upon one or two others.

Between H and D_3 there are three coronal rings that show with certainty at λ 3987, λ 4231, and λ 5303. In addition, four other rings are suspected in this region, while a number of inner coronal arcs are visible. The ultra-violet rings at λ 3644 and λ 3802 do not show very distinctly.

Probably the most interesting features shown by the films taken with the 6-inch concave grating spectrograph are the details shown by the green coronal ring, and to a less extent by some others. In the green coronal ring there are at least 15 or 20 small streamers or projections, the most remarkable of which is a narrow streamer starting from the Moon's limb at latitude about 35° or 40° south of east, and stretching for about 5 minutes of arc as a slightly in-curved streamer toward the northeast, just crossing the solar equator. This streamer shows with certainty upon five films, and it is thought to be faintly visible in the ultra-violet ring at λ 3382. In the ring at λ 3454 there are some slight defects on the best film where the streamer would show.

There are a number of small projections or short streamers at various latitudes, and the region of the equator on both the east and west sides shows very bright patches, particularly the west sides.

Another striking feature of the green coronal ring showing plainly upon the second, third and fourth films, but not so well upon the fifth and sixth, is a nearly radial dark streamer with a strong bright streamer to the south of it and a small bright streamer to the north of it. The dark streamer starts from the Moon's limb at about latitude 55° or 60° south on the Sun's east limb. The photographs with the 15-foot camera show a dark radial streamer or rift with bright streamers each side of it at the same place, and they are without much doubt identical. The narrow curved streamer is apparently not to be seen in the coronal photographs, although they have not been compared with short exposures showing faint detail in the inner corona. The dark radial streamer shows upon all the photographs of the corona

which have been examined, but the spectrograms show it much the best, and most extensively upon the second and third exposures, and hardly at all upon the sixth exposure. An examination of the four films indicates that the phenomenon was a comparatively short-lived one. It can be seen in the coronal ring at λ 3382 also. The coronal ring in the green shows no connection whatever with prominences, and only with part of the streaks of continuous spectrum, and the evidence at hand indicates that there is only a partial correspondence with the inner corona as shown upon photographs.

Next in interest is the ultra-violet chromospheric spectrum. Some lines are visible between λ 3000 and λ 3100, and a great many from that on toward the visible spectrum. Prominent among the lines in the extreme ultra-violet part of the spectrum are those due to titanium, chromium, manganese, and scandium. Among the more interesting and stronger lines in the extreme ultra-violet are the chromium lines at $\lambda\lambda$ 3132.2, 3125.1, 3120.5, and 3118.8.

Upon the best film taken at Guelma the farthest lines which can be detected are manganese lines at λ 3035.5 and λ 3038, which are, however, so faint as to be more or less uncertain. The helium lines are prominent throughout the spectrum.

(2) A 5-inch concave grating of 12 feet radius and 10,000 lines to the inch, mounted horizontally and fed with light from the mirror of a cœlostat. This grating was used with a slit, and as it was intended particularly for coronal radiations, it was thought best instead of a single radial slit to use a multiple slit composed of four slits so placed as to cross the corona at $12\frac{1}{2}°$ on each side of the equator, one pair on the west and the other on the east limb of the Sun. This was done in order to stand a better chance of having at least one of the slits cross those parts of the corona where the material producing the coronal rings happened to be brightest. The light from the cœlostat mirror was condensed upon the slit by a 6-inch parabolic reflector of 15 feet radius, and a similar reflector was used to render the light parallel after passing through the slit and before falling on the grating.

The development of the exposures made with the multiple-slit spectrograph showed that, in spite of the precautions taken in diaphragming, the films received light other than that diffracted from the grating, so that the development could not be carried far enough to

show all that the films would have shown otherwise; also the grating was not bright enough to give sufficient light to show the coronal lines with certainty. Nevertheless, one film shows considerable detail, about 16 hydrogen lines appearing with one of the slits, and the hydrogen line near H exhibiting the separation from that line very sharply. There is also an indication of motion in the line of sight in both directions with some of the lines. The other slits were not over as bright regions of the chromosphere or prominences, do not show so much, and do not show any line-of-sight motion. The lines showing motion are due to prominences on the east limb. The coronal spectrum appears as continuous spectrum, the grating not being bright enough to show distinct coronal lines with certainty.

The lines on the films are quite sharp, and since they were made with a slit and the position of the lines is not affected by the distribution of matter in the chromosphere, they should give very good determinations of wave-length, especially for the ultra-violet hydrogen lines.

There were three exposures made with this spectrograph:

First exposure from 5^s after totality to 30^s after; duration 25^s.
Second exposure from 35^s after totality to 3^m after; duration 2^m 25^s.
Third exposure from 3^m 5^s after totality to 3^m 30^s after; duration 25^s.

The first film gives the most in the way of results; the second one shows the coronal spectrum to be for much the greater part continuous; and the third film was a defective one, having spoiled from some cause. However, some lines can be seen upon it.

(3) A 4-inch concave grating of 10 feet radius and 1000 lines to the inch. This instrument was used direct with a Cramer "Trichromatic" plate in a sliding plate-holder, and was mounted on the polar axis. The results with this instrument were unsatisfactory.

The 6-inch concave grating used at Porta Coeli, the 5-inch and 4-inch grating, used at Guelma, and the 6-inch parabolic reflectors were secured through the kindness of Professor J. S. Ames, of the Johns Hopkins University.

In the visual observations made with the direct-vision spectroscope, the yellow helium line D_3 was particularly prominent. Particular attention was paid to the yellow helium line, the green-blue hydrogen F, the red hydrogen line C, and the green coronal line.

Much to the observer's surprise, the yellow helium line was very nearly as strong as the two hydrogen lines, and remained visible throughout the total phase of the eclipse. It was nearly as prominent throughout as either of the hydrogen lines, none of them, however, forming a complete ring, but being visible in patches due to prominences. The lines D_3 and F ($H\beta$) show on the spectrograms taken at mid-eclipse, but the yellow helium line, because of the comparative insensitiveness of the film to the yellow, is not nearly so prominent relatively to F as it was to the eye.

The green coronal line was carefully observed, but the spectrograms show as much as was visible to the eye, except that the extent or height about the Moon's limb was somewhat greater as seen with the spectroscope than is shown upon the spectrograms. The very bright patches connected with the green coronal ring and the streaks of continuous spectrum shown on the spectrograms were distinctly visible in the spectroscope.

The Fraunhofer crescents as seen with the spectroscope became distinct about seven minutes before the second contact, and D_3 and the hydrogen lines became bright lines about one and a half or two minutes before. By that time the dark bands through the spectrum in the direction of its length, due to irregularities of the Moon's limb, had begun to cut up the Fraunhofer crescents very much, and it became evident that second contact would occur earlier than had been calculated. After second contact the smaller bright lines faded rapidly, those of medium length more gradually, and the green magnesium lines lasted faintly until near mid-totality. The green coronal ring attracted attention as soon as totality began.

POLARISCOPIC OBSERVATIONS

Polariscopic work was carried on at only one of the stations, at Guelma, Africa, and was in charge of Dr. N. E. Gilbert, of Dartmouth College. The principal object of these observations was to determine the amount and distribution of polarized light in the corona. An attempt was also made to verify the observations of Mr. and Mrs. Newall[1] to the effect that an abrupt change takes place in the direcrection of polarization of sky-light at the beginning and end of totality,

[1] *Proc. R. S.*, 67, s. 365, 1901.

but it became necessary to intrust these observations to an assistant from the men of the "Dixie," and the results were unsatisfactory.

For the observations upon the corona two instruments gave satisfactory results.

a) A "*photo-polarigraph.*"—This consisted of a photographic camera with a Nicol prism placed before the objective. The Nicol used was an exceptionally fine one with an aperature of 3.8cm. This was mounted, free to rotate, upon the front of the camera base, and a handle attached to the case was provided with stops so that the Nicol could be set quickly, even in the dark. The objective, placed immediately behind the Nicol, was an achromatic lens 8 cm in diameter and 85 cm in focal length. The plates used were 4×5 inch Seed "Gilt Edge." The instrument was mounted upon the large polar axis.

Two exposures were made, one of 10 seconds and one of 30 seconds in each of three positions of the Nicol separated by 45°. All of the six negatives show a dense ring of light about the Moon's disk. This shades off uniformly in all directions at first, then more rapidly in the direction parallel to the principal plane of the Nicol. In the direction perpendicular to the principal plane streamers can occasionally be traced nearly two diameters from the disk.

Comparing these negatives, certain points stand out sharply. Inside of four or five minutes of arc the intensity shades off uniformly on all sides of the Moon's limb. No sign of polarization is visible. Beyond this limit the proportion of polarized light increases rapidly. In the direction perpendicular to the principal plane of the Nicol, i. e., in the direction in which the Nicol allows radially polarized light to enter, the depth of continuous corona varies from12′ to 17′, with an average of 13′; while in the direction parallel to the principal plane the depth varies from 8′ to 10′, with an average of 9′.5, a difference of 3′.5 depending upon the Nicol. This difference serves to give the image of the continuous corona a distincly elliptical form in every negative. If we average separately the short and the long exposures, we find, for the direction perpendicular to the principal plane, 12′.3 and 14′ respectively, and for the direction parallel to the principal plane 9′.3 and 9′.7 respectively. Increasing the exposure threefold has added 13.1 per cent. to the extent in the former direction, and 4.12 per cent. in the latter direction. Too much weight should not be placed upon the

exactness of these figures, but it is safe to say that practically all of the light beyond 10′ of arc in the continuous ring is polarized radially.

The amount of light in the streamers which is not polarized radially is small. On account of the great irregularity in the position, extent, and brightness of the streamers averages would mean but little. In the following table have been collected the figures representing the extent to which the most prominent streamer in each of four directions is visible on the negatives:

No. of Negative	Exposure	Transmitted Light Polarized	N.	S.	E.	W.	Extent of Inner Corona	
							N. and S.	E. and W.
1	10^s	N.–S.	28′	44′	12′	12′	12′	10′
3	10^s	E.–W.	12′	12′	28′	32′	10′	12′
5	30^s	N.–S.	32′	50′	15′	12′	13′	10′
6	30^s	E.–W.	24′	18′	28′	40′	10′	12′

Negatives No. 2 and No. 4 are omitted because no plates were taken with which they can be compared directly. Averaging the figures for these four streamers, we have for extension beyond continuous corona:

Extension on side of transmitted light . . . . . 23′
Extension on side of "extinguished" light . . . . 4′.6

These figures indicate that practically all the light in the streamers is polarized radially. For increase in length due to increasing threefold the time of exposure:

Increase on side of transmitted light . . . . . . 4′.5
Increase on side of "extinguished" light . . . . 5′.2

This increase is practically the same in the two directions. The exact amounts are difficult to measure on account of fogging of the background, in the long exposures, by sky-light.

The value of observations such as these for the study of polarization depends wholly upon the possibility of making direct comparisons between negatives taken under conditions as nearly as possible identical. Two negatives taken in succession lose something in value on this account. Double image prisms as fine as the Nicol used in the polarigraph at Guelma are extremely rare, but two images taken simultaneously with the same instrument would allow more minute comparison of details, and so would possess advantages which would partly compensate for the defects of a poorer crystal.

b) *A "spectro-polarigraph."*—This consisted of an ordinary 45-degree prism spectroscope with a photographic attachment, a Nicol prism being placed immediately behind the slit. This was also mounted upon the polar axis. The slit, $\frac{1}{10}$ mm wide, was placed across the center of the Moon's disk, parallel to the Sun's equator. Two exposures, on the same plate, were made, the length of each being $1^m\ 25^s$. The Nicol was rotated 90° between exposures.

No 1. Principal plane of Nicol perpendicular to slit. Light polarized radially in equatorial regions of the corona transmitted.

On the east side of the Moon's limb are some nine bright lines due to the prominence which covered the slit at this point. These are much overexposed. They can be identified roughly by superposing the plate upon a reference plate taken from sky-light before the eclipse. The H and K lines are very strong, and the others appear to coincide, as expected, with prominent hydrogen and calcium lines. No trace of these lines appear on the west limb. It was hoped that traces of dark Fraunhofer lines might be found on this plate, but none appears.

The continuous spectrum covers the region from about λ 5200 to λ 3800. It is very strong, being overexposed, and extends over about a half diameter on either side of the Moon's limb. The contrast with the companion negative on the same plate is most striking.

No. 2. Principal plane of Nicol parallel to slit. Light polarized radially not transmitted.

Only faint traces of two bright lines, probably the H and K lines so strong in No. 1, are visible. The absence of these lines is probably due to the fact that the prominence was covered before this exposure was made. No Fraunhofer lines were expected, as all light except that from the inner corona was excluded by the Nicol.

The length of the continuous spectrum is practically the same as in No. 1, but it is only 6′ wide, and much weaker near the outer edges. This plate verifies fully the results derived from the photo-polarigraph plates; i. e., there is no appreciable amount of polarized light inside of 4′ or 5′, but beyond 6′ or 7′ practically all the light is polarized radially.

Conclusions.—The six plates obtained with the photo-polarigraph and the two with the spectro-polarigraph are entirely consistent and satisfactory. They supplement and confirm completely the results

obtained in recent eclipses. The quantitative results are quite definite. Inside of five minutes of arc there is practically no light polarized radially. This, then, is not reflected light, but the source is self-luminous matter, very largely solid, as is shown by the strong continuous spectrum. Between five and ten minutes of arc the amount of polarized light increases very rapidly, showing that the light is reflected sunlight. The presence of the dark Fraunhofer lines in the outer corona has been so often demonstrated that the absence of these lines on my plates proves nothing against these conclusions. An instrument with better definition would doubtless have obtained them.

METEOROLOGICAL OBSERVATIONS

All the meteorological work connected with the expedition was in charge of Professor F. H. Bigelow, of the U. S. Weather Bureau.

Complete records of the pressure, temperature, relative humidity, wind, direction and velocity, amount and kind of clouds, were secured for the astronomical stations at Daroca, August 5-31; Porta Coeli, August 3-31; Guelma, August 4-31; and for the auxiliary meteorological stations at Zaragoza, August 14-31; Guadalajara, August 14-31; Tortosa, August 23-31; Castellon partial records during August, and Bona throughout the month; also on the ocean voyages in both directions. The weather during August was very favorable till August 29, when a rain storm covered Spain, and disturbed the normal conditions which it was hoped would prevail for two days longer. On August 30 there was partial cloudiness, the eclipse being wholly or partly obscured at Castellon, Tortosa, and Zaragoza, but seen clearly at Porta Coeli, Daroca, and Guadalajara; also at Guelma and Bona, Africa.

The effect of the shadow upon normal conditions of the atmosphere cannot be studied as fully as desired on account of this disturbance in Spain. On the day of the eclipse especially complete records were made at all the stations by the co-operation of the Spanish officials in charge of the observatories at Tortosa, Zaragoza, Guadalajara, and Castellon. Generally the pressure was undisturbed, the temperature fell about 8° F. at Daroca, and Porta Coeli, and less at the other stations, the relative humidity increased, the cloudiness increased, but no effect on the wind was noted to be of significance.

Long series of observations were made on the atmospheric electricity, including the electric potential gradient, the number and velocity, of the ions and the general electrical conductivity. The polarization was observed for several days at Daroca, and the radiation was measured at Guelma. On the ocean voyage were secured seven kite ascensions on the outward trip and one on the homeward trip. The electrical conditions were observed continuously on the homeward voyage; also some radiation and polarization readings were made on the ocean. It has been shown that good results can be obtained with the actinometer and the polarimeter at sea in moderate weather.

MAGNETIC WORK

Magnetometers and dip circles were established at Porta Coeli, Spain, and at Guelma, Algeria, and series of observations were made for several days preceding and on the day of the eclipse, the latter, especially, involving very delicate and laborious work. From 10 A. M. to 4 P. M. on August 30 eye-readings of the declination needle were made once a minute, with frequent readings of the thermometer, and during totality readings were made every fifteen seconds. The two midshipmen detailed for this arduous duty were Mr. N. H. Wright at Guelma, and Mr. J. H. Lofland at Porta Coeli, and their results will be taken up for study as soon as practicable.

U. S. Naval Observatory,
Washington, D. C.,
January 30, 1906.

A GREAT PHOTOGRAPHIC NEBULA NEAR π AND δ *SCORPII*

By E. E. BARNARD

Through the courtesy of Professor Hale and the generosity of Mr. John D. Hooker, of Los Angeles, I spent the past spring and summer in photographic work at the Solar Observatory of the Carnegie Institution on Mount Wilson, California, at an altitude of 6000 feet. Mr. Hooker's generous grant made it possible to transport the Bruce Photographic Telescope of the Yerkes Observatory to Mount Wilson, where it was installed from February until September, 1905. It is hoped that the results may later be published in full, with reproductions of the principal photographs. At this time I wish to call attention to an especial region in *Scorpio.*

The main object of the work at Mount Wilson was to secure the best possible photographs of the Milky Way as far south as the latitude would permit. But little time was available for independent investigations in other parts of the sky, though the conditions for such work were often superb.

A few exposures were made, however, at various points in a search for diffused nebulosities. The extraordinary nebulosities in *Scorpio* and *Ophiuchus* which I found by photography in 1894—those of ρ *Ophiuchi*, ν *Scorpii*, etc.—suggested the immediate region of the upper part of the Scorpion as a suitable hunting-ground. Trial plates were exposed on ρ *Scorpii*, and π *Scorpii*, and elsewhere. The photographs of the region of π showed a very remarkable, large, straggling nebula extending from π to δ *Scorpii*, with branches involving several other naked-eye stars near.

With the exception of the great curved nebula in *Orion* and some of the exterior nebulosities of the *Pleiades*, this nebula is quite exceptional in its extent, and in the peculiarities of its various branches. A simple description of it would be inadequate to give a fair conception of these features.

It is difficult to properly reproduce the photograph because of the

PLATE X

N

E

W

GREAT PHOTOGRAPHIC NEBULA NEAR π AND δ *SCORPII*

1905 April 29 and 30. Exposure $8^h\,45^m$ Scale: $1^\circ = 23.3$mm.

faintness of some of the extensions of the nebula. Enough can be shown, however, to give some idea of its general structure (Plate X).

The plate from which the reproduction was made was exposed on two nights. These were 1905, April 29, $18^h\ 52^m$ to $23^h\ 12^m$, and April 30, $18^h\ 32^m$ to $22^h\ 52^m$, G. M. T. The photograph was therefore given a total exposure of $8^h\ 40^m$. The conditions during the exposures were not especially good. The sky was whitish during the first exposure, with some mist. On the second night the sky hazed up and stopped the exposure. The position was far south and over the valley and the ocean. Had I been more fortunate in the selection of the nights for this long exposure, I am confident that the extent of the nebula would have been much greater, for the plate shows but little more nebulosity than is shown on two other plates with half the exposure time. Had this photograph been made on some of the superb nights that came later on, I think the extensions of the nebula might have been carried beyond the dimensions of the plate, for besides the portions that are clearly shown, vague suggestions of it can be traced to much greater distances.

The brightest portion of the nebula lies about $\frac{1}{2}°$ south of π *Scorpii*. It is a rather long, wavy mass, inclined some 40° to the southwest. This portion has a narrow extension for nearly a degree to the east, and a curved arm extends upward to π. A larger diffused mass, well defined at its east side, extends from the southwest of π north to the 6.7 mag. star *Cord. DM.*—24°.12365. This portion covers a wide area to the south and west, where it fades insensibly into the sky. A diffused branch extends to and beyond the 5.3 mag. star *Cord. DM.* —25°.11131. The 5.5 mag. star *Cord. DM.*—24°.12352 has a brightish mass extending to the southwest some 15′ or 20′. From this last star the nebulosity curves northward and east to the 5.8 mag. star *Cord. DM.*—24°.12354, and thence in a straggling manner northeast to δ *Scorpii*, and for a degree beyond that star. From the stream running to δ an irregular broader mass runs east for a degree or more. The full extent of the nebula north and south is about $4\frac{1}{2}°$ or 5°. There is a diffusion of the nebulosity for some distance to the east of δ.

The 5.3 mag. star, 13 *Scorpii*, is strongly nebulous on this photograph (and on two other plates), but falls outside the limits of the

present reproduction. This star is *Cord. DM.*—27°10841, and its place for 1875.0 is

$$\alpha = 16^h\ 4^m\ 36^s.6\ ,\quad \delta = -27^\circ\ 35'.7\ .$$

There are also two trails (one for each night) of the same asteroid on this plate in about $\alpha = 15^h\ 42^m \pm$, $\delta = -23^\circ.6 \pm$. These trails will be found 61.5 mm from the upper edge and 27 mm and 31 mm, respectively, from the right-hand edge of the plate.

A striking fact in connection with this nebula is that all the larger stars connected with it, whose spectra have been observed, are of the *Orion* type. Professor Frost informs me that the *Orion* stars, from the peculiarities of their spectra, are thought to be in a primitive condition, and are the most likely—as is shown also by photography—to be associated with nebulosities, while the converse seems to hold for stars of the more advanced types of spectra.

Though some of the stars on this plate are doubtless only apparently connected with the nebula, there seems to be no doubt that others are really in the nebula.

In thinking over this object recently, I recalled the fact that in photographs of ν *Scorpii*, which I made at the Lick Observatory in 1895, there were traces of nebulosity about π *Scorpii* which I did not have the opportunity to investigate further at the time. An examination of these plates shows that the brighter mass close to and south of π is visible. The image of that star is in the region of bad spherical aberration. The extended branches are too far west to be on the plates.

The present photograph was made with the 10-inch Brashear lens of the Bruce photographic doublet.

Such nebulæ as this one, and others of similar branching, straggling appearance, rather tend to make one doubt the generally accepted form of the nebular theory. Indeed, this theory seems to have been built mainly upon the the visual appearance of the nebulæ when seen in very inferior telescopes. It seems to me doubtful if the nebular theory would have been constructed at all if at that time our present knowledge of the appearance of the nebulæ, as shown by photography, had been available. It has always seemed to me that the

nebular theory accounts for the existence of the stars in a very strained manner, and that it has very little to commend it.

While there are some of the nebulæ (I do not speak now of the spiral nebulæ) that seem to agree in appearance with the theory, there is a much larger percentage that seem to be directly opposed to it. It does not appear necessary that the association of a star and a nebula proves that the star was formed from the nebula.

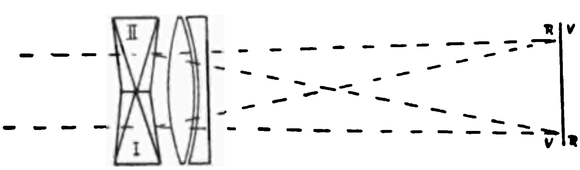
YERKES OBSERVATORY,
February 6, 1906.

A PROPOSED METHOD FOR THE DETERMINATION OF RADIAL VELOCITIES OF STARS

By GEORGE C. COMSTOCK

The following discussion presents in somewhat greater detail the substance of a communication made by the writer to the New York meeting of the Astronomical and Astrophysical Society of America, held December 28-30, 1905. It deals with the problem of determining differentially the radial velocities of many stars by comparison of their spectra obtained with an objective-prism, with the spectrum of a star of known velocity simultaneously impressed upon the same photographic plate.

In the accompanying figure let I represent a direct-vision prism placed in front of one-half of an objective, and let the broken line passing through I represent a pencil of light coming from the standard reference star, *S*, and producing a spectrum, *RV*, upon a photographic plate placed in the focal plane of the objective. Let II represent a similar prism placed in front of the other half of the objective, with its refracting edge turned in the opposite direction, and producing upon the plate a spectrum, *VR*, of the same source, *S*. The two spectra of *S* thus produced will be superposed and crossed, the violet end of one falling upon the red end of the other, and by a suitable construction of the prism any assigned part of one spectrum may be made to coincide with the corresponding part of the other. Let α, β, γ be any three lines in the spectrum of S, preferably so chosen that the wave-length of β is approximately equal to the mean of the other two wave-lengths, and let λ', λ'', λ''' represent these wave-lengths. Denote by α_{I}, γ_{II}, etc., the distance from an arbitrarily assumed origin to the image of α, γ, etc., produced on the plate by the prism marked I or II in the figure, this distance being measured parallel to the length of the spectrum. It is obvious that these distances will depend upon a



considerable number of determining factors, e. g., the construction and adjustment of the prisms, I and II; the wave length, λ, corresponding to the line in question; and other quantities which, collectively, we may represent by the symbol C. We represent this dependence by the equations,

$$\begin{aligned} \beta_{\mathrm{I}} &= \phi\,(\mathrm{I},\ C, \lambda'') \\ \beta_{\mathrm{II}} &= \phi\,(\mathrm{II}, C, \lambda'') \end{aligned} \qquad (1)$$

and denoting by ψ a new function produced by subtraction of the ϕ's we obtain,

$$\beta_{\mathrm{II}} - \beta_{\mathrm{I}} = \psi\,(\mathrm{I}, \mathrm{II}, C, \lambda'') = b\ . \qquad (2)$$

It is obvious that the symbol b defined by this equation represents the linear distance on the plate between the two images of the line β. If we now consider another object, in the spectrum of which the same line β is found, we may write for it

$$\beta'_{\mathrm{II}} - \beta'_{\mathrm{I}} = \psi\,(\mathrm{I}, \mathrm{II}, C, \lambda''_{\mathrm{I}}) = b'\ . \qquad (3)$$

If the second object possesses a radial velocity sensibly different from that of the first, the wave-lengths λ'' and λ''_{I} will differ slightly, and putting $\lambda''_{\mathrm{I}} = \lambda'' + (\lambda''_{\mathrm{I}} - \lambda'')$,

$$b' = \psi\,(\mathrm{I}, \mathrm{II}, C, \lambda'') + \psi' \cdot (\lambda''_{\mathrm{I}} - \lambda'')\ , \qquad (4)$$

where

$$\psi' = \frac{d}{d\lambda}\psi\,(\mathrm{I}, \mathrm{II}, C, \lambda'')\ . \qquad (5)$$

Subtracting Eq. (2) from Eq. (4) we obtain

$$b' - b = \psi' \cdot (\lambda''_{\mathrm{I}} - \lambda'')\ . \qquad (6)$$

To determine, numerically, the function ψ' we write Eq. (2) for the α and γ lines in the spectrum of S, as follows:

$$\begin{aligned} \alpha_{\mathrm{II}} - \alpha_{\mathrm{I}} = a = \psi\,(\mathrm{I}, \mathrm{II}, C, \lambda'') + \psi' \cdot (\lambda' - \lambda'') + \tfrac{1}{2}\psi'' \cdot (\lambda' - \lambda'')^2 + \text{etc.} \\ \gamma_{\mathrm{II}} - \gamma_{\mathrm{I}} = c = \psi\,(\mathrm{I}, \mathrm{II}, C, \lambda'') + \psi' \cdot (\lambda''' - \lambda'') + \tfrac{1}{2}\psi'' \cdot (\lambda''' - \lambda'')^2 + \text{etc.} \end{aligned} \qquad (7)$$

where a and c are quantities analogous to b, and find, when the intervals of the λ's are sufficiently small and approximately equal,

$$a - c = \psi' \cdot (\lambda' - \lambda''')\ , \qquad (8)$$

which determines ψ' in terms of measurable quantitites when the wave-lengths of α and γ in the source S are known. It may be noted that a constant error in the values of these wave-lengths, or a small error in the assumed radial velocity, does not sensibly affect the determination of ψ'.

We now have from Equations (6) and (8),

$$\lambda''_1 - \lambda'' = \frac{(b'-b)\,(\lambda'-\lambda''')}{a-c}\,, \tag{9}$$

and representing by $v_1 - v$ the difference in the radial velocities of the two stars, by V the velocity of propagation of light, and introducing the Doppler principle,

$$\frac{\Delta v}{V} = \frac{\Delta\lambda}{\lambda}\,,$$

we obtain,

$$v_1 = v + \frac{V(\lambda'-\lambda''')}{a-c} \cdot \frac{b'-b}{\lambda''}\,. \tag{10}$$

Representing by C the coefficient of the last term in Eq. (10),

$$C = \frac{V(\lambda'-\lambda''')}{a-c}\,, \tag{11}$$

we note that this coefficient may be regarded as a factor characteristic of the plate and standard star, and that its value may be derived from any pair of lines in the spectrum of any star chosen as the standard. When so derived it relates to the point of the spectrum midway between the lines in question, and it is obvious that if a number of values of C are obtained, distributed throughout the spectrum, there may be found from these by interpolation the value required for use in connection with any particular line β that may be measured in the spectrum of another star. Equations (11) and (10), written in the form,

$$v_1 = v + C \cdot \frac{b'-b}{\lambda''}\,, \tag{12}$$

therefore constitute a solution of the problem, but the adequacy of this solution remains to be determined by experience. It may prove necessary to deal more rigorously with the determination of the function ψ'; and, on the other hand, it may prove possible to obtain such stability of instrumental adjustment as to warrant a calibration of the apparatus, a constant curve for the determination of ψ', that may be employed at several successive settings, thus obviating the necessity of a standard star on every plate. It lies beyond the scope of the present paper to develop considerations of this kind or to discuss the numerous practical details and possible difficulties attending the application of the method here proposed. Some of these, such as the

effect upon the spectra produced by temperature changes, the advantage of substituting a doublet in place of the single objective shown in the figure, etc., have already been suggested by others. The author hopes to deal experimentally with all such considerations affecting the observational side of the method. In case these difficulties shall prove not insurmountable, the advantages of the method are obvious, e. g., the possibility of dealing with many stars at a single exposure and of extending determinations of radial velocity to stars much fainter than any hitherto investigated.

WASHBURN OBSERVATORY,
MADISON, WIS.,
January, 1906.

MINOR CONTRIBUTIONS AND NOTES

ON THE SPECTRUM OF THE SPONTANEOUS LUMINOUS RADIATION OF RADIUM. PART IV: EXTENSION OF THE GLOW[1]

In our second paper[2] we suggest "whether the β-rays, which are analogous to the cathode corpuscles, may not be mainly operative in exciting the radium glow. On this surmise it would be reasonable to expect some little extension of the glow outside the limit of the solid radium itself. We are unable to detect any halo of luminosity outside the limit of the solid radium bromide; the glow appears to end with sudden abruptness at the boundary surface of the radium." We omitted to state that this conclusion was arrrived at by eye observations. The radium was observed in the dark with a lens, and with a low-power microscope.

The earlier photographs of the spectrum of the glow were taken, for the purpose of comparison spectra, with the height of the slit reduced by shutters so as to be within the width of the exposed radium bromide, and, therefore, these photographs would not show whether the bright bands of nitrogen extend into the air beyond the radium. Subsequently photographs were taken with the whole height of the slit, and on these we find that all the bands of nitrogen do extend to some little distance outside the radium salt. Our attention at the time being directed to other phenomena of the glow, we did not examine the photographs to see if the nitrogen bands extended beyond the radium.

In a paper, dated August 22, 1905, F. Himstedt and G. Meyer[3] state that in the photographs of the spectrum of $RaBr_2$, the four nitrogen bands, $\lambda\lambda$3577, 3371, about 3300, and 3159, extend beyond the radium salt, while the other less refrangible bands are not traceable outside the radium. In our photographs all the nitrogen bands project beyond the radium salt; the relative distance to which the extension can be detected in the case of each band being, as might be expected, in proportion to the strength of the impression of that band upon the photographic plate.

[1] From advance proofs of a paper communicated to the Royal Society, December 12, 1905.

[2] *Proc. R. S.*, **72**, 410, 1903; *Astrophysical Journal*, **18**, 390, 1903.

[3] *Ber. d. Nat. Gesells. Freiburg*, **16**, 13–17, 1905.

B. Walter and R. Pohl, in a paper dated September 1905,[1] give an account of experiments made with the help of screens, which show that for a distance of up to about 2 cm, the air surrounding radium bromide has an action on a photographic plate.

On re-examining an early photograph, taken in 1903 for another purpose which is described in our second paper,[2] in which the $RaBr_2$ was enclosed in a very narrow tube of thin glass, we find that the bands of nitrogen, which are strong within the tube, show no trace of extension on the plate beyond the tube. The exposure of this plate was seven days.

This experiment, which we have repeated recently with an exposure of fourteen days, shows that the luminosity of nitrogen in the near neighborhood of radium bromide is not due to the cathode-like β-radiation, for this passes freely through glass.

Two explanations may be suggested: first, that the active cause is the α-rays;[3] or, secondly, that the nitrogen molecules which encounter those molecules of the radium which are undergoing active changes are broken up into ions, which are projected outward, and give rise to the glow of luminous nitrogen[4]

SIR WILLIAM AND LADY HUGGINS.

OBSERVATIONS MADE WITH SELENIUM CELLS DURING THE TOTAL SOLAR ECLIPSE OF AUGUST 30, 1905[5]

During the total solar eclipse of August 30, 1905, a series of observations was made with selenium cells at the Observatory of the Ebro, near Tortosa, Spain, for the double purpose of determining by their means the variation of the quantity of the Sun's light, and of recording the exact instants of the beginning and ending of totality.

I. THE VARIATION OF THE QUANTITY OF THE SUN'S LIGHT

The electric conductivity of selenium is known to be affected by the light of the Sun, especially by its red rays: yellow and green rays have less influ-

[1] *Ann. der Phys.*, **18**, 406, 1905. [2] *Proc. R. S.*, **72**, 412, 1903.

[3] B. Walter, July 1905, showed by means of absorption screens that the radiation from radio-tellurium can produce the ultra-violet light of nitrogen. *Ann. der Phys.*, **17**, 367.

[4] The experiments described in our last paper showed that probably the β-rays are not the operative cause of the nitrogen glow. *Proc. R. S.*, **76**, 488, 1905; *Astrophysical Journal*, **22**, 204, 1905.

[5] "Zwei Beobachtungen mittels Selenzellen bei der totalen Sonnenfinsterniss am 30. August 1905," by Th. Wulf and J. D. Lucas, S. J., *Physikalische Zeitschrift*, **6**, 838-847, 1905. Translated, condensed and diagrams redrawn by William F. Rigge, S. J., Creighton University, Omaha, Neb.

ence upon it, while violet and ultra-violet, as well as infra-red, have none whatever. As it is pretty safe to assume that all the spectral colors of the Sun are diminished equally during an eclipse, the quantity of solar light is directly proportional to the electrical conductivity of selenium. This assumption, however, will not hold for the light received during the early morning and late evening hours, since the red rays are then present in greater proportion. While a selenium eye would therefore see the twilight too strongly, it is true that in general its power of perception is the same as that of the human eye, since both are sensitive to nearly the same colors. For this reason the perception of our visual sense may properly be supplemented and corrected by measurements made with selenium.

Apparatus.—The selenium cell used in these investigations was a flat one made by Ruhmer in Berlin six months ago. It was fastened upon the mirror of a heliostat, which was made to face the Sun directly.

A battery of five storage cells was placed in series with the selenium and a D'Arsonval galvanometer made by Siemens and Halske. The latter had a resistance of 84 ohms and was in shunt with 0.4 ohm. The resistance of the selenium cell varied between 2000 and 30,000 ohms. The current was therefore directly proportional to the conductivity of the selenium. Replacing the selenium cell by a known resistance determined its absolute conductivity and also the accidental changes in the battery.

Method of observing.—The observations were carried on during the entire day of the eclipse, from an hour before sunrise until after sunset. They were made generally at intervals of half an hour, but at much shorter intervals at the times of the Sun's rising and setting and during the partial phase of the eclipse, while during the total phase they were carried on continuously.

The measurements were made in this way. First the battery was tested by inserting a resistance-box of 2221 ohms in place of the selenium. This regular test was found to be necessary during the forenoon because the battery was used also for other purposes at the Observatory. Later on, however, all other circuits were interrupted and the battery proved to be very constant, especially during the time of the eclipse.

After this test of the battery, the resistance of the unilluminated selenium cell was measured, then the cell was exposed to the light for a minute and its resistance measured again, and finally the battery was again examined.

The selenium cell was covered up immediately after each exposure except just before totality, when a large number of measurements of its conductivity was made in rapid succession.

Fig. 1 is a graphic representation of the results. The numbers denote

the hours of Greenwich time, B and E the moments of first and last contact respectively, and T the period of totality. The upper curve shows the conductivity of the illuminated or bright selenium, and the lower that of the unilluminated or dark. The diagram shows that the periods of rest allowed the selenium were not at all sufficient to completely restore its "dark resistance." It is interesting, however, to notice that as the brightness of the midday Sun is being diminished by the eclipse ($B-T$), the conductivity of the dark selenium is also on the decrease. The difference of the ordinates of the two curves therefore gives a more accurate picture of the actual intensity of the light at the time.

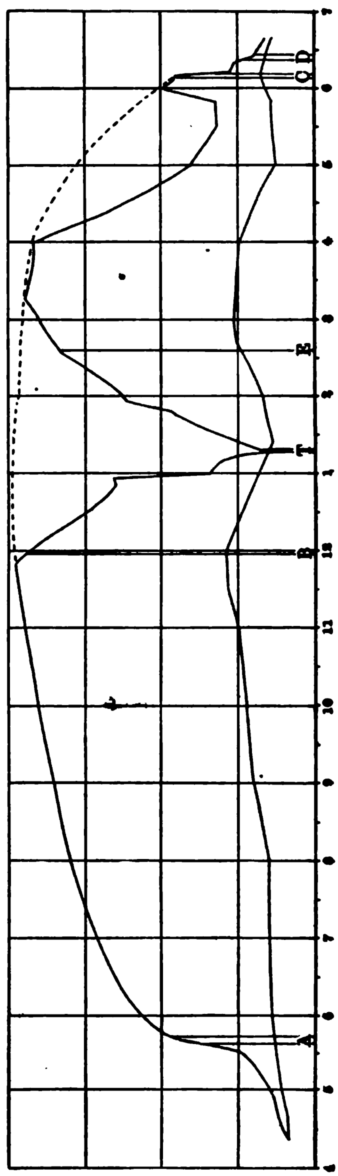


FIG. 1.

As the conductivity of the selenium changes very rapidly when illuminated, but not so rapidly when darkened, the previous condition of the cell is of special importance when the intensity of the light is on the decrease. By increasing luminosity, however, its conductivity always rises nearly to its maximum within a minute, no matter what the condition of the cell may be.

Discussion.—A study of the curves of Fig. 1 gives the following account of the quantity of sunlight on the day of the eclipse. As the morning dawn occurred in an entirely clear sky, the time of sunrise shown on the diagram may be considered typical. We see that the curve begins with a gradual slope, thus indicating the "astronomical dawn." Toward $5^h\ 15^m$ the slope begins to increase in steepness—the Sun's rays reflected and refracted by the atmosphere already strike the place: this is the "civil dawn." At about $5^h\ 37^m$

the first direct rays of the Sun fall upon the apparatus, and the conductivity of the selenium increases rapidly (point *A* on the diagram), until the whole of the Sun's disk is visible.

From now on the intensity of the sunlight is continually increasing, on account of the lessening distance it has to run through the atmosphere, until shortly before 12 o'clock, when the eclipse begins.

At the beginning of the eclipse the sky was still clear. That the selenium should already begin to react at this time (point *B* on the diagram) was entirely unexpected, since a partial eclipse does not diminish the general luminosity to an extent noticeable to the eye. Later on, of course, we might expect a diminution of light, and a sudden and precipitous loss at the moment of totality. It was therefore with no little astonishment that the galvanometer needle was seen to move immediately after the first contact, and for nearly an hour to indicate a uniformly increasing resistance.

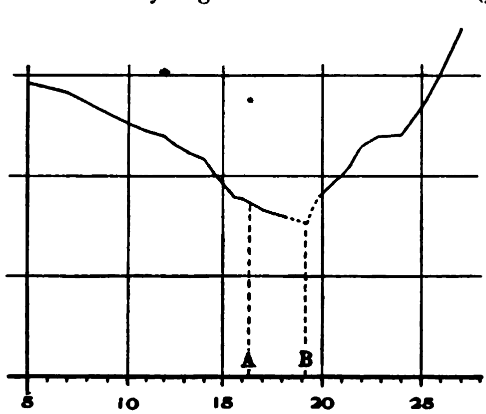


FIG. 2.

About half an hour before totality, clouds began to form and at times to cover up the Sun, thus producing the corners in the descending branch of the curve. Observations were now made in greater number in order to obtain as complete as possible a record of the variation of the light. Fig. 2 gives this part of the curve on an enlarged scale. The numbers are the minutes after 1 o'clock. The figure shows in a most interesting and instructive manner that the luminosity decreased uniformly until the darkness of totality. This latter does not show itself on the curve by a sudden descent (*A*), as had been expected; but, on the contrary, the beginning of totality was characterized by the fact that the luminosity, which had before steadily decreased, now no longer did so, but remained remarkably constant. The diagram, indeed, still shows a descent during totality, but this is owing to the selenium itself, which, as is well known, does not after an exposure to light regain its maximum resistance at once, but only after a long period of rest. For this reason, as a matter of fact, the lowest point, *B*, of the curve occurs at the end of totality, and must of necessity be indicated with extraordinary sharpness. Unfortunately no reading was taken

at the very end of totality, at $1^h\ 19^m$. It is therefore necessary to remark distinctly that the dotted part of the curve has been drawn by extrapolation, since the entire behavior of the selenium, as well as the observations to be noted in the second part of this paper, do not admit of any other course, inasmuch as no light whatever could act upon the cell between $1^h\ 18^m$ and $1^h\ 19^m$. After the period of totality there is no abrupt change in the slope, as figure 2 shows, but the strength of the current increased gradually in the same proportion as the Sun's disk was being uncovered.

However probable and self-evident the explanation given may appear, it is nevertheless entirely at variance with observations made hitherto. The question then arises how it is that the events of an eclipse appear to us so very differently. The answer is not difficult. Our eye does not perceive all kinds of luminosities with the same facility. When strong impressions are already acting upon it, it is not sensitive to small variations, but it does perceive them very strongly when the other impressions disappear. For this reason we are very sensitive to the last rays of the disappearing Sun, and the variation of the luminosity at this moment seems to us to be very much greater than during the whole time preceding. According to this explanation it would seem that our eye is the most appropriate instrument for the observation of this moment. It would be so in fact if we could also record our perceptions without loss of time. But as personal errors are different with different individuals and at different times, and especially as they are entirely beyond determination at the critical moments of an eclipse, automatic contrivances are evidently to be preferred to the eye.

As the second half of the eclipse coincided with a gradual clearing of the sky, and as a selenium cell regains its maximum conductivity only slowly, even with a strong illumination, the last contact, *E* on Fig. 1, cannot be recognized by its means.

Toward 4 o'clock in the afternoon clouds began again to form and take away a great part of the light. From about 6 o'clock until the end of the observations the sky was clear again. Sunset occurred on August 30 at $6^h\ 23^m$. But as Tortosa is surrounded, especially in the west, by a long mountain chain, which attains an altitude of 1180 meters in Mount Espina, 13 kilometers distant from the place of observation, the curve in Fig. 1 shows a precipitous descent at the point *C* shortly after 6 o'clock. It is remarkable, however, that in spite of this the astronomical sunset, *D*, is also recognizable by another rapid descent in the curve.

For the purpose of completing this investigation and bridging over the gap caused by the eclipse, these observations were repeated at the same spot on several following clear days. The results are indicated in Fig. 1 by the

dotted line. At 1 o'clock a diminution of the noon-day brightness is noticeable. The time of the greatest luminosity probably coincides exactly with that of apparent noon, but on account of what might be called the inertia of the selenium cell the measures obtained in the afternoon are somewhat too large.

The above results, expressed in terms of the conductivity of the selenium cell, were now to be transformed into those of candle-power. This was done at the Electrotechnic Institute of the high school at Aachen, by comparing

FIG. 4.

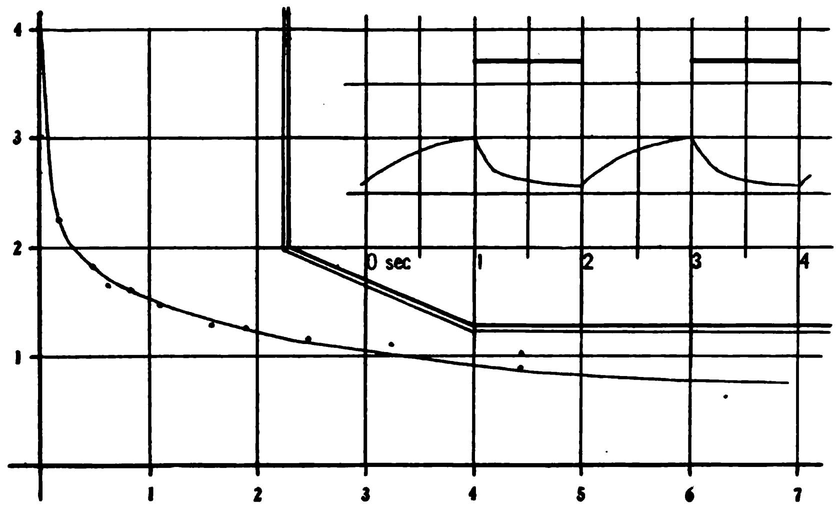


FIG. 3.

an incandescent electric lamp and a gas flame with the amylacetate lamp of the selenium apparatus. Fig. 3 gives the results, the unit used for the ordinates being 10,000 ohms and that for the abscissae 100 candle-power.

In determining the luminosity of sunlight by means of this curve, values are found which are certainly too small. Thus the maximum light shown at $11^h\ 45^m$ on Fig. 1 would be only 7000 candles, while other and direct measurements record the brightness of a Spanish noon as being much higher. The difference is owing entirely to the colors of the various lights. Thus the electric and the gas lights are especially rich in red rays, which act most strongly upon selenium; while sunlight contains much more blue and violet, which scarcely act upon selenium at all, and even the yellow and green rays, which are the strongest in the Sun, have less effect upon it. It would therefore be a great mistake to use an electric lamp to determine the conductivity

of selenium, and then to use this conductivity to find the brightness of sunlight, for this would be only to determine the brightness of those rays which act upon selenium. For this reason the numbers shown on Fig. 3 are not to be regarded as absolute, but only as characteristic of selenium. If, however, we assume that the light during totality has the same wave-lengths as the dawn, its brightness would be the same as that of the sky 30 or 45 minutes before sunrise.

II. THE INSTANTS OF THE BEGINNING AND END OF TOTALITY

The second use made of selenium during the eclipse was for the accurate determination of the instants of the beginning and end of totality. Since optical telephony shows that the conductivity of selenium changes in less than the thousandth part of a second, it became necessary to use a very rapid galvanometer, to record its performance continuously at known moments, and to employ entirely automatic and frictionless apparatus.

Apparatus.—A highly sensitive photographic film was moved with a uniform speed of 12 mm per second past a horizontal slot, through which a cylindrical lens impressed a sharp line of about 0.3 mm in width upon the film. A piece of glass ruled with lines a millimeter apart, and placed almost in contact with the film, also drew upon the latter a series of lines parallel to its length and direction of motion.

The galvanometer consisted of a steel horseshoe magnet with a silvered quartz thread drawn between its poles. The sensitiveness of this thread was such that when the current which traversed it was made or broken, less than 0.01 second sufficed to restore it to its former position. Its resistance was about 5000 ohms, but 10,000 additional ohms were inserted in series with it in order to protect it against being heated by the current. An acetylene lamp illuminated the quartz thread, and a microscope, along with the cylindric lens, projected an image of it on the photographic film.

The selenium cell, also by E. Ruhmer, was cylindrical in shape and placed in the focus of a parabolic mirror. As it was necessary to use a very feeble current in order not to injure the silvering of the quartz fiber; and as it was also desirable to vary the current as much as possible in order to increase the amplitude of the oscillations of the thread, a Wheatstone's bridge arrangement was adopted such that two selenium cells were inserted into the opposite arms of the bridge and the resistances so proportioned that the current was made to traverse the galvanometer first in one and then in the opposite direction. The battery used consisted of four large bichromate cells, and gave 8 volts and about one milliampere.

The sunlight obtained from a heliostat was first brought to a focus by

a lens. Then the divergent beam was divided, the larger part falling through green glasses upon the selenium cell, and the less through the cylindric lens upon the photographic film. When the sunlight was intercepted at the focus by an opaque screen, it was cut off simultaneously from both the selenium and the film. This arrangement, which made it possible to examine the instantaneous behaviour of the selenium cell when darkened and when illuminated, consisted of a piece of blackened sheet-metal about 4 cm square, attached to the pendulum rod of a clock, which was allowed to swing through the focus. In case the light should not have been interrupted exactly for a whole second nor symmetrically at the beats of the pendulum, the middle of the dashes drawn upon the photographic film and the middle of the vacant spaces would certainly represent the intervals of a second. A few arbitrary interruptions of the light at known times served to identify the seconds.

Fig. 4 is a diagram of a part of the photographic record. (The original was too faint to admit of reproduction.) The vertical lines represent intervals of half a second. The two upper horizontal lines were made by the clock. They are each one second long and one second apart. The lower curve was made by the selenium and the quartz fiber. The clock and selenium records differ less than 0.1 second. The figure also shows how rapidly the resistance of the selenium diminishes upon exposure, and how slowly it increases in the dark. The regularity of the motion of the film was such that no differences of 0.5 mm or 0.04 second in the lengths of the second marks were discovered. Some few lateral displacements, however, of about 0.1 second were found in several places, caused probably by the motion of the wheel-work in the chronograph. They rather facilitated the comparison of the clock and galvanometer records.

The rapidity with which the selenium reacted, and the entirely automatic and frictionless character of the apparatus, would seem to mark this method of determining the interior contacts in an eclipse as the most accurate attainable. Indeed, it held out prospects of recording not only all of the Sun's prominences, but even the shadow bands which are seen at the beginning and end of totality. But the results actually attained by this method in the present instance were sufficiently satisfactory for its first employment.

One of its main advantages lies in the fact that it can be used to some extent with a cloudy sky, when all other methods fail completely. This unfavorable condition was experienced at this very eclipse at the beginning of totality, when clouds began to form and to blur the curve on the film; in spite of this, however, the instant of the beginning of totality was re-

corded with satisfactory certainty. While it cannot be noticed on the film by the eye, a microscopic examination locates it beyond all doubt. The end of totality was of course recorded with a much greater distinctness, both because of the action of the selenium itself, and because of the disappearance of the clouds.

A diagram of the photographic film (which was too faint for reproduction) is shown in Fig. 5, in which, however, the ordinates are on a scale one hundred times that of the abscissae. The points *B* and *E* indicate the beginning and end of totality. The numbers are the full minutes after one o'clock.

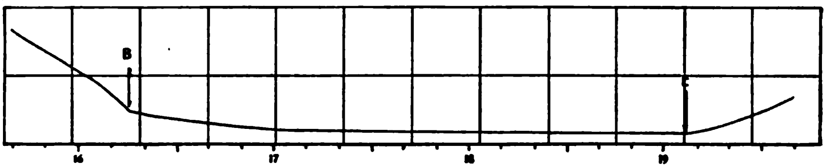


FIG. 5.

The selenium method agrees with visual observation in showing that the observed moments of totality were considerably fast of the computed ones. The following are the computed and observed times of the total phase. They, as well as all the times used in this paper, are Greenwich Mean Times, the longitude of Tortosa being $1^m\ 58^s.6$ east of Greenwich.

	Computed	Observed by Selenium Method
Beginning	$1^h\ 16^m\ 30^s.18$	$1^h\ 16^m\ 15^s.6$
End	1 19 20.51	1 19 6.9
Duration	2 50.33	2 51.3

The results attained by this employment of selenium sufficiently show the practicability of the method. A series of such apparatus placed along the line of totality of an eclipse would not only eliminate all the personal errors of observation, but would also do away with the difficulty of determining what precise degree of obscuration was called by various observers the beginning or end of totality. While the precise moment actually recorded by the selenium cell would call for a more accurate investigation, the results would, even independently of this, be at least comparable with one another.

RECENT FORMULÆ FOR DISTRIBUTION OF SPECTRUM LINES IN SERIES

Within the last three years two spectral formulæ of some importance have been proposed to represent spectral series, one by W. Ritz in 1903, and the other by J. Halm in 1904. The first was designed to represent the series of lines found in line-spectra, while the other was intended to apply to the series of lines found in both line- and band-spectra. Both formulæ possess many advantages over the older ones.

(*a*) The formula proposed by Ritz[1] is of the form

$$\pm \nu_m = A - \frac{N}{\left\{ m+a+\frac{b}{(m+a)^2}+\frac{c}{(m+a)^2}+\text{etc.} \right\}^2},$$

where ν_m is called the wave-frequency of the line "m," and is equal to $\frac{10^8}{\lambda_m}$, if λ_m is measured in Ångström units; A, a, b, c are constants for any one series; N is the universal Balmer's constant, 109675; and m is the sequence of natural numbers, each of which is associated with one spectral line in the series. It is based to some extent upon theoretical considerations. The theory, however, as Rayleigh[2] has remarked, has the appearance of being a highly artificial one. Starting with Balmer's and Rydberg's formulæ[3] for the hydrogen series, and aided by a number of more or less arbitrary assumptions, Ritz arrives at the following expression for all substances which give line-spectral series:

$$\pm \nu = N \left\{ \frac{1}{p^2} - \frac{1}{q^2} \right\},$$

where p and q are roots of certain transcendental equations, and are expressible in the form of the semi-convergent series, $p=n+a_1+\frac{b_1}{p^2}+\ldots$ and $q=m+a_2+\frac{b_2}{q^2}+\ldots$. If, as a first approximation, we put $p=n+a_1$ and $q=m+a_2$, we obtain Balmer's and Rydberg's formulæ. As a second approximation we obtain

$$\pm \nu = N \left\{ \frac{1}{\left(n+a_1+\frac{b_1}{n^2}\right)^2} - \frac{1}{\left(m+a_2+\frac{b_2}{m^2}\right)^2} \right\}.$$

[1] *Ann. der Phys.*, (4) **12**, 264, 1903.

[2] *Phil. Mag.*, (6) **11**, 122, 1906.

[3] Kayser, *Handbuch der Spectroscopie*, **2**, 504, 570, 572. Ritz, *Ann. der Phys.* (4) **12**, 266, 1903.

If n is taken as constant, this becomes

$$\pm\nu=A-\frac{N}{\left(m+a_2+\frac{b_2}{m}\right)^2}\ .$$

It is in this form that the formula was applied in practice. Upon incorporating in it the relations discovered by Rydberg[1] to hold between the principal and second subordinate series, a single formula is obtained for the two,

$$\pm\nu=N\left\{\frac{1}{\left(n+a_1+\frac{b_1}{n^2}\right)^2}-\frac{1}{\left(m+a_2+\frac{b_2}{m^2}\right)^2}\right\},$$

where $m=1.5$, $n=2, 3, 4, \ldots$ for the principal series, and $n=2$, $m=1.5, 2.5, 3.5, \ldots$ for the second subordinate series. In this form it also represents the first subordinate series except that the constants a_2, b_2 are different and $n=2$, $m=3, 4, 5, \ldots$ The values which n and m assume here for the three series are the same as those used by Balmer and Rydberg[1] in their formulæ for the hydrogen series.

There are a number of advantages of the Ritz formula over the others: (1) it makes N a universal constant for line-spectra; (2) it involves fewer constants, six for the *three* series instead of nine as required by the Kayser and Runge formula: (3) it is compatible with the identical magnetic behavior[2] and intensity relations so far observed in the case of the principal and second subordinate series; and (4) it most accurately represents the data so far as it has been applied. To give some idea of its relative accuracy when compared with the Kayser and Runge formula, the following table has been taken from Ritz's article[3] (it is typical of similar comparisons which he made for the other elements):

LITHIUM

PRINCIPAL SERIES

m	λ	ν	F	K. and R.	Ritz
2	6708.2	14903.1	0.2	+108.0	0.00*
3	3232.77	30924.4	0.03	0.00*	0.00*
4	2741.39	36467.3	0.03	0.00*	0.07
5	2562.60	39011.5	0.03	0.00*	0.00*
6	2475.13	40390.0	0.1	−0.2	0.20
7	2425.55	41215.5	0.1	−0.01	0.01
8	2394.54	41749.3	0.2	+0.3	0.03
9	2373.9	42112.0	—	+0.75	0.10
10	2359.4	42370.7	—	+1.18	0.22

[1] Rydberg, Paris Reports, **2**, 212, 1900. Ritz, *Ann. der Phys.*, (4) **12**, 270, 1903.

[2] Runge and Paschen, *Astrophysical Journal*, **20**, 123, 1904.

[3] *Loc. cit.*

SECOND SUBORDINATE SERIES

m	λ	ν	F	K. and R.	Ritz
1.5......	6708.2	14903.1	0.2	+615.0	0.00
2.5......	8127.3	12300.8	—	−65.0	0.75
3.5......	4972.11	20106.7	0.1	0.00*	0.00*
4.5......	4273.44	23393.8	0.2	0.00*	−0.08
5.5......	3985.94	25081.2	0.2	0.00*	−0.04
6.5......	3838.3	26046.0	3.0	−0.2	+2.1

Tail of Principal Series $(\nu_\infty) = 43482.8$
Tail of Second Subordinate Series $(\nu_\infty) = 28579.7$

In this table the symbols m, λ, ν are respectively the index-number, wave-length, and wave-frequency of the series-lines; F is the experimental error; and "K. and R." and "Ritz" stand for the difference (observed λ − calculated λ), as determined respectively by the two formulæ. The lines marked with a star were used to calculate the constants of the formulæ. All the data given were taken by Ritz from Kayser's *Handbuch der Spectroscopie.*

The table shows that the Ritz formula has a marked advantage in accuracy over the Kayser and Runge formula, especially for the lines at the red end of the series. That the formula satisfies the Rydberg relations is shown in the table by the facts that both series start with the same line and that the wave-frequency distance between the tails of the two is equal to the wave-frequency of the first line in the principal series. It is interesting to note that the second line in the second subordinate series lies to the red side of the first line in the same.

The foregoing formula led Ritz to predict the positions of certain lines in the spectra of the alkali metals. Last year Saunders[1] found that of his new lines two coincided very closely with Ritz's predictions.

(*b*) The formula proposed by Halm[2] to represent the series in line- and band-spectra was an empirical one. It is as follows:

$$\frac{1}{\nu_\infty - \nu_m} = a(m+\mu)^2 + b \ ,$$

where ν_m is the so-called wave-frequency of the line "m" in the series; a, b, ν_∞ are constants for any one series, ν_∞ being the wave-frequency of its tail; and μ is some constant, usually zero. Because it is a modification of Rydberg's[3] line-series formula and Thiele's[4] band-series formula, he called it the "Rydberg-Thiele" formula. He applied it to all of the known series of line- and band-spectra, and found it to hold in most cases within the errors of observation. In those *line-series* where the agreement was not

[1] *Astrophysical Journal*, **20**, 188, 1904.
[2] *Edin. Trans.*, **41**, III, 555, 1905.
[3] Kayser, *Handbuch der Spectroscopie*, **2**, 516. [4] *Ibid.*, **2**, 483.

good his formula still represented the data as well as, or better than, the Kayser and Runge formula. He evidently did not know of the Ritz formula, for in his comparisons he does not refer to it, and yet it represents the data (so far as it has been applied) uniformly better than his own. For line-series the Ritz formula has all of the advantages, mentioned under (*a*), over the Rydberg-Thiele formula; for the latter only approximately satisfies the Rydberg relations and, as a rule, requires twelve constants for the three series.

In applying the formula to band-spectra all of the known series of carbon and oxygen were tried, and the formula was found to represent them to within a few hundredths of an Ångström unit. The greatest number of lines in any of these series did not exceed fifty. When applied to the cyanogen band at $\lambda = 3883$, which contains 170 lines, the agreement, Halm says, was excellent up to the 80th line, quite satisfactory up to about the 140th, but beyond this the discrepancies increased enormously, showing that the formula was not applicable to the whole band. Upon dividing the band into three parts, or branches, he found that each branch could be accurately represented by the formula. His results show, however, that, as in the case also of some of the other carbon and oxygen bands, the index-number of the first visible line in the series is a comparatively high number, showing that, apparently, many lines in the series are missing.

On the basis of Lester's[1] work on the oxygen bands, Halm is led to conclude that this cyanogen band is made up of three branches which overlap, but with the result that one of them apparently obliterates the other in the region common to the two. This sudden dropping off on the head side, or tail side, of a band-series is not rare. Nevertheless it does not seem to me to be the case in this cyanogen band, for, if it were, we should not expect the uniform decrease in intensity from one end of the band to the other.

While not so good for line-series as the Ritz formula, the Rydberg-Thiele formula is undoubtedly the best formula for band-series so far proposed. It serves also to emphasize the close relationship existing between line-spectra and band-spectra.

T. S. Elston.

Johns Hopkins University,
February, 1906.

[1] *Astrophysical Journal*, **20**, 81, 1904.

THE ASTRONOMICAL AND ASTROPHYSICAL SOCIETY OF AMERICA

The seventh meeting of the society was held in New York City on December 28, 29, and 30. Papers were read at four well-attended formal sessions, with the president of the society, Professor Newcomb, in the chair. The list of papers presented is as follows:

David Todd, "*Saturn* as Seen with the Eighteen-Inch Clark Refractor of the Amherst College Observatory."

S. I. Bailey, "Some Variable Star Problems."

Annie J. Cannon, "Maxima and Minima of Variable Stars of Long Period."

E. C. Pickering, "Systematic Study of Faint Stars."

G. C. Comstock, "Distribution of the Stars."

F. H. Seares, "Photometric Investigations."

Mrs. W. Fleming, "Some Peculiar Stellar Spectra."

Eric Doolittle, "The Hough Double Stars."

E. B. Frost, "Professor Burnham's Forthcoming General Catalogue of Double Stars."

C. L. Poor, "The Figure of the Sun."

J. A. Parkhurst and F. C. Jordan, "Photographic Photometry of Rapidly Changing Variable Stars."

S. A. Mitchell, "Results from Spectrograms at the Spanish Eclipse, 1905."

E. B. Frost, "Observations of Radial Velocities of Stars."

G. H. Peters, "Solar Coronas Observed at the Porta Coeli Station of the U. S. Naval Observatory Eclipse Expedition, 1905."

N. E. Gilbert, "Polarized Light in the Corona, Eclipse of 1905."

C. C. Trowbridge, "Resemblances between Persistent Meteor Trains and the Afterglow from Electrodeless Discharges."

E. E. Barnard, "Vacant Regions of the Sky."

G. C. Comstock, "A Proposed Method for the Wholesale Determination of Velocities in the Line of Sight."

E. C. Pickering, "Determination of Absolute Positions of Stars by Photography."

D. Todd and R. H. Baker, "Local Predictions for the Total Eclipse of 1907 in Turkestan and Mongolia."

J. A. Brashear, "On Some Evidences of Permanent Set in Optical Surfaces."

F. H. Seares, "The *Polaris* Vertical Circle Method of Determining Time and Azimuth."

Eric Doolittle, "Determination of the Errors of Adjustment of the Polar Axis of the Equatorial."

David Todd, "On the Practical Requisites for Securing Perfect Definition in Eclipse Photography."

E. B. Frost, "Observations of Sun-Spots by the Late C. H. F. Peters."

D. Todd and R. H. Baker, "Computed Tracks and Totality-Durations of Total Solar Eclipses in the Twentieth Century."

A. O. Leuschner, "An Analytical Method of Determining the Orbits of Satellites."

W. H. Pickering, "The Theory of Planetary Inversion."

C. G. Abbot, "A Standard Pyrheliometer and its Use on Mount Wilson, California."

B. L. Newkirk, "Tables for the Reduction of Photographic Measures."

R. T. Crawford, "A Contribution on Astronomical Refraction."

Sarah F. Whiting, "A Solar Planisphere."

B. L. Newkirk, "Investigation of the Repsold Measuring Apparatus of the Students' Observatory."

W. W. Dinwiddie, "The Forty-Foot Camera of the U. S. Naval Observatory Eclipse Station at Guelma, Africa."

C. D. Perrine, "Polarization Observations of the Corona of August 30, 1905."

F. Schlesinger and G. B. Blair, "Note on Anomalous Refraction."

Henrietta S. Leavitt, "New Variable Stars in the Small Magellanic Cloud."

R. S. Dugan, "Magnitudes and Mean Positions of 359 *Pleiades* Stars."

David Todd, "Results of Amherst Eclipse Expedition to Tripoli, 1905."

M. B. Snyder, "The Philadelphia Observatory and the Disastrous Fire of March 9, 1905."

LETTER FROM PROFESSOR CALLENDAR

My attention has been called to a statement by Mr. G. T. Walker contributed to the Oxford meeting of the International Union for Co-operation in Solar Research with regard to one of my Sunshine Recorders, which does not appear to represent the facts. I had no opportunity of correcting this statement at the time, and it has received very wide circulation among those interested in the subject without contradiction. In view of the importance of a full discussion of all promising methods of recording the solar radiation, I trust you will be able to allow me space for a reply.

Mr. Walker complains that a particular instrument of the old type with removable cover made in 1898 has been damaged by condensation of water

vapor, that the black has peeled off the wires, and that the constants of the instrument have altered. I have looked up the case of this particular instrument, and can only conclude that Mr. Walker has been misinformed. I find a letter from the observer in charge, dated February 1902, stating that the apparatus was working extremely well. Neary two years later it was returned to England for the redetermination of its reduction factor, which the makers had omitted to supply in the first instance owing to some misunderstanding. *The instrument was found to be in perfect condition, the coating of black on the wires was quite uninjured, and there was no evidence whatever of any alteration in its reduction factor.* We do not, as a matter of fact, recommend this type of receiver for use in damp climates, because, not being hermetically sealed, there is risk of damage from condensation, in case the observer in charge omits to renew the drying material periodically according to instructions. The hermetically sealed type is certainly preferable in this respect, but is open to the objection that it cannot so easily be repaired in case of damage in transit. But if, as Mr. Walker states, water was allowed to collect and drop on the wires, it is certainly surprising that the instrument should have endured such treatment for so long a time without any evidence of alteration. It seems unfair, however, to blame the instrument or condemn the method.

H. L. CALLENDAR.

ROYAL COLLEGE OF SCIENCE,
LONDON, S. W.,
October 26, 1905.

NOTE ON PROFESSOR NEWCOMB'S OBSERVATIONS OF THE ZODIACAL LIGHT

Professor Newcomb's paper on the zodiacal light north of the Sun in the October number of this *Journal*, has interested me much, and I have wondered if certain observations made here do not have reference to the same phenomenon. At the summer solstice the Sun passes 24° below our north horizon at midnight. The old assumption that twilight ends when the Sun is 18° below the horizon would not permit any twilight effect here at midnight. Yet every summer that we have been here I have observed for a week or two in midsummer a twilight glow passing along the north horizon for a couple of hours in the middle of the night. I have watched this move from the west under the pole to the east, being apparently the evening twilight passing along the north horizon to join the dawn. This extends several degrees above the horizon at midnight. The extent along the horizon may at that time be as much as 15° or 20°. In explanation of this I had

assumed that the twilight effect was not really confined to the 18° limit, and that it must extend at least 30° from the Sun.

I have thought, since reading Professor Newcomb's article, that what I have seen is probably identical with what he observed in Switzerland; and therefore it may possibly be a zodiacal effect. Hereafter I shall make special observations of the phenomenon, to try to decide whether it is purely atmospheric twilight or a manifestation of the zodiacal light. The phenomenon is in no wise a difficult one to observe.

After I had communicated with Professor Newcomb on the subject, he kindly suggested that the following note be appended to mine.

E. E. BARNARD.

YERKES OBSERVATORY,
January 17, 1906.

NOTE BY PROFESSOR NEWCOMB

There is of course no absolute proof that the light visible along the north horizon at midnight, when the Sun is at a depression of 25°, more or less, is not a form of twilight. The phenomena of meteors show that the atmosphere, or an atmosphere of some kind, surrounds the earth to a height of more than 100 or perhaps 200 miles. The reflection of the Sun's rays from this rare atmosphere would produce a similar effect; but I think this is not the cause of the phenomena, for these reasons:

1. Careful observation when the zodiacal light makes the greatest angle with the horizon show that as the horizon is approached, its breadth rapidly increases at such a rate as, if continued, would bring it far enough north of the Sun to be visible under the circumstances we have mentioned.

2. The rapid diminution and disappearance of twilight when the Sun is somewhere between 15° and 18° below the horizon seems to show that this is the end of actual twilight.

REVIEWS

Spectroscopy. By E. C. C. BALY. London and New York: Longmans, Green & Co., 1905. Pp. xi + 568, with 163 figures. $2.80.

The appearance of this volume in the series of "Textbooks of Physical Chemistry," edited by Sir William Ramsay, reminds one that, in its earlier days, spectroscopy was largely, if not primarily, a branch of chemical science. So true was this at least that, in 1886, chemists reckoned among the noteworthy properties of the then newly discovered *germanium* the fact that it was *not* discovered by use of the spectroscope. But one has only to turn the pages of the present volume to be impressed with the wide divergence between the "spectrum analysis" of Bunsen's time and the spectroscopy of the present; for its pages bristle with mathematical formulæ and mechanical considerations which chemists used to regard as *foreign* but which they now label *domestic*.

Briefly the volume may be described as an excellent scholarly compendium of terrestrial spectroscopy brought up to date. The subject of astrophysics is barely touched upon. Of the seventeen chapters which the treatment includes, the first seven are devoted to what might be called ordinary spectroscopic practice, including the theory and use of the prism and the diffraction grating; the remaining ten chapters are given to more advanced and special problems, such as those occurring in the infra-red and ultraviolet regions, spectroscopic sources, the Zeeman effect, spectral series, etc. Concerning each of these chapters it may be said that the problem is always definitely stated, the English is clear and simple, and the references to original sources are ample.

Besides having given a rather extended description of apparatus, the author has woven into the text, in an interesting manner, practically all of the established principles of the subject. Nor, indeed, has he limited himself to *known* principles; for many mooted points and needed investigations are suggested.

The chapters on "Series," on "The Zeeman effect," on "Interference Methods," on "Spectrum Photography," and on "The Infra-Red" appear especially valuable; they have a "practical" air about them such as might be expected from a man who has spent much time in experimental contact with the subject. But the two chapters on "The Production of Spectra"

and on "The Nature of Spectra"—to which the author's own work has contributed so largely—are possibly the most interesting ones in the entire book. They contain important suggestions for anyone working in the optical laboratory. The complete details and precautions given for filling vacuum tubes will be appreciated by many.

The following remark on p. 36 needs correction in any future edition: "Rowland was led to his work on gratings by his invention of a very accurate method of cutting a screw, which, of course, is the basis of all dividing engines such as are used for ruling gratings." It is generally considered a matter of history that the sequence of ideas was just the reverse of this. In his search for monochromatic illumination(in a study of phosphorescence, as your reviewer has heard it) Rowland saw that a good grating was a necessity. The key to a good grating he recognized in a perfect screw; and hence set to work to make one.

As to the eight pages (166–174) devoted to the theory of the concave grating, one can hardly avoid feeling that these might well be replaced by the more elegant and simple treatment given by Runge in Winkelmann's *Handbuch der Physik.*

The spark-coil, or open magnetic circuit transformer devised by Rowland in 1886 and represented in Kayser's *Spectroscopie*, Bd. I, p. 183, Fig. 39, is so easily made, and is such a powerful and useful source, that its description might well find place in any chapter on production of Spectra.

The section on "The Reversal of Spectral Lines" is excellently illustrated by one of the author's own photographs. The explanation, based on experimental evidence, which Humphreys (*Astrophysical Journal* **18**, 204, 1903) has offered for double reversals, and his opinion that true double reversals "seldom, if ever, occur in arc spectra," would have added interest to this paragraph.

The volume as a whole is characterized by a fine perspective and by always putting the emphasis in the right place. It should find a place in the library of every student of physical optics.

HENRY CREW.

Beiträge zur Photochemie und Spectralanalyse. By J. M. EDER and E. VALENTA. Halle: Wilhelm Knapp, 1904. Pp. xvi+858; with 93 figures in the text and 60 plates, 25 in heliogravure. Bound, M. 25.

This massive volume renders available to the general scientific public the valuable series of papers which have been contributed by the authors, for the most part to the Vienna Academy of sciences. The work is divided

into five parts: I, spectroscopic investigations; II, sensitometry and photometry of the chemically active rays, and solarization; III, behavior of the silver salts to different parts of the spectrum; IV, spectroscopic studies of the photographic three-color printing; V, investigations of printing colors.

The spectroscopist and physicist will find the work of very great service, particularly the first part, which contains in 418 pages (of size 17×25 cm) the authors' well-known researches upon the spectra of the elements, in which the wave-lengths are given in clear tabular form, with the results of other observers for comparison. The reproductions of spectra represent the highest perfection of the art, and were executed in the *k.k. Graphischen Lehr- und Versuchsanstalt* in Vienna, of which the authors are respectively director and professor. The first paper is dated as presented to the Academy in 1890, and the last paper, which discusses the invariability of wave-lengths in the spark and arc spectrum of zinc, was communicated to the Academy at the end of 1903.

Some of the longer papers in this part deal with the following topics: on the visible and ultra-violet emission spectrum of faintly luminous hydrocarbons (the Swan spectrum) and of that of the oxy-hydrogen flame; on the utility of the spark spectra of different metals for determining the wave-lengths in the ultra-violet; on the line-spectrum of elementary carbon; on the different spectra of mercury, and the spectra of copper, silver, and gold; spectroscopic investigation of argon; the spectra of sulphur; normal spectra of certain elements for wave-length determinations in the extreme ultra-violet.

The second part, devoted to photographic effects of light, which occupies 174 pages, presents investigations of very high value to all who are making scientific applications of photography. Among the topics treated in the different papers are the following: new chemical photometer for the ultra-violet rays in daylight; investigations on the chemical action of light; determination of the sensitometry of orthochromatic plates with Scheiner's sensitometer; a system for the sensitometry of photographic plates (in four sections); phenomena of solarization in spectrum photography. Mention should be made of the beauty of the reproductions of the opacity-curves for photographic plates given in this section, in which the squares of the co-ordinate paper are printed in blue.

Many of the papers in Part III were published in the *Photographische Correspondenz*, and a few brief papers were contributed by others than the authors. The authors have also added some papers which had not appeared elsewhere. The field is one in which the authors speak with

eminent authority, and this part will be of great utility to technical photographers, and others interested in the correct rendering of colors. Among the topics treated are: behavior of the halogen compounds of silver in respect to the solar spectrum; spectrographic investigation of standard sources of light; on methods of photographing the spectrum with bromide of silver plates; investigations of the sensitizing power of different coal-tar products for bromide of silver dry plates; the action of different yellow dyes as sensitizers. Diagrams are given in the text whereever needed, and the processes and instruments employed are described in a clear manner. It is a cause for congratulation to all workers in the fields touched upon in this volume that, through the particular official relationship of its authors, this splendid volume can be issued at the price of 25 marks, which is insignificant as compared with the normal cost of publication. The type is all of the beautiful font which makes the reading of the publications of the Vienna Academy a particular pleasure. No spectroscopist or student of scientific photography can afford to be without this book, and the very few libraries (if any), which may contain all of the published works of the authors, need have no fear of duplication in securing this superb volume, representing the collected works of these Austrian savants. E. B. F.

Mathematical and Physical Papers. By G. G. STOKES. Volume V. Cambridge: The University Press; New York: The Macmillan Co., 1905. Pp. xxv + 370, with portrait.

This volume concludes the reprint of the scientific papers of the late Professor Sir George Gabriel Stokes. The first volume of these reprints appeared in 1880, and we now have in these five volumes practically every scientific paper of Stokes. Various semi-popular lectures given at various occasions have been omitted, but no important printed contribution has been overlooked.

This fifth volume of Stokes's papers has been prepared for the press by Dr. Larmor, and has been enriched by a biographical sketch of Stokes which was contributed by Lord Rayleigh to the obituary of the Royal Society, by a photographic portrait, and by a series of examination papers and problems which had been set at various times by Stokes in the University of Cambridge.

In this volume there are not many papers of special interest to investigators in spectroscopy, although it contains the Wilde lectures on the nature of the Roentgen rays, the interesting memoir on the crystalline reflection of

crystals of chlorate of potash, and many shorter papers on questions dealing with the intensity of solar radiation.

To the student of physics every paper in the volume is of interest, and not the least so are the various facts either in the text or in notes by Dr. Larmor in connection with the examination questions. To one interested in the history of mathematics and physics the volume is of the greatest importance. The biographical sketch of Stokes by Lord Rayleigh is one of the most interesting and important contributions to the history of physics that have appeared in recent years, and the appreciation in it of the relative value of Stokes's contribution to knowledge is most interesting.

J. S. AMES.

Newcomb-Engelmanns Populäre Astronomie. Dritte Auflage. Herausgegeben von DR. H. C. VOGEL. Leipzig: Wilhelm Engelmann, 1905. Pp. x+748. Figs. 198, including 12 plates. 15 Marks; bound, 16 Marks.

This is the second edition of this admirable work which has been prepared by Director Vogel of the Astrophysikalisches Observatorium at Potsdam, and it has been enlarged and revised to include all important researches of the ten years which have elapsed since the previous edition appeared. Based upon the best modern popular astronomy for serious-minded readers, the revisions and enlargements which it has undergone make it easily the best reference work available on astronomy and astrophysics. It can be especially commended to workers in allied branches of science and to the general reader as representing a judicial and sufficiently complete statement of the present known facts of astronomy.

There has been no attempt to make the work popular in the sense of giving a superficial treatment, although of course no mathematical knowledge is presupposed on the part of the reader. The work does not assign to each fact or discovery the name of the investigator, which will doubtless prove to be a decided convenience to the non-technical reader, to whom questions of priority are not matters of importance.

Additional value has been lent to the book by the co-operation of the reviser's friends. Thus Professors Dunér and Küstner examined the second edition carefully and made suggestions for the new edition. Professor Young contributed his views on the constitution of the Sun, as he did to Professor Newcomb's original work in 1877. Professor Seeliger has written a section on the structure of the universe; and Professor Kapteyn also gave to Professor Vogel an expression of his views on the same sub-

ject. Messrs. Kempf, Eberhard, and Ludendorff also rendered important assistance in the preparation of the new edition.

The illustrations are excellent; many of them are new. The tabular statements, which occur in various parts of the work, are fully brought to date and will prove of value to professional astronomers. The list of proper motions exceeding 1″ on pages 510 to 512 is a case in point; other valuable tables are those of binary stars whose orbits have been determined; also those of spectroscopic binaries.

Brief biographical sketches of deceased astronomers occupy the last fifty pages of the book, and add to its value. An appendix contains tables of the elements of the planets and comets, and lists of the brighter variable stars, binary stars, double stars, nebulæ, and clusters.

It is to be hoped that the distinguished author of the original work may feel disposed to give us a new edition in English; for this edition in German, after these revisions at the hand of one of the most eminent living astrophysicists, is lacking only in its availability for those who do not readily read the German language.

F.

Manual of Advanced Optics. By C. RIBORG MANN. Chicago: Scott, Foresman and Co., 1902. Pp. 196; with 41 figures. $2.

There has existed the serious need of a book dealing with those methods of measurement that are based on the interference of light-waves. One has been compelled in the past to depend upon the rather meager descriptions of these methods that are given in the original articles. The present book to a large degree fulfills this need. It is divided into eighteen chapters, and has a short appendix and an index. The first six chapters deal with optical measurements by the direct use of interference patterns. The subjects treated are: limit of resolution, the double slit, the Fresnel mirror, the Fresnel bi-prism, the Michelson interferometer, and the visibility curves. The next four chapters take up the use of the prism and grating. Chapters eleven to fifteen inclusive cover experiments on the subject of polarized light, while the sixteenth treats of spectrophotometry. The last two chapters deal with the interesting subjects: "The Development of Optical Theory" and "The Trend of Modern Optics." The appendix contains tables and a description of some necessary laboratory manipulations.

Each chapter begins with a brief treatment of the theory involved and emphasizes the physical principles rather than the mathematics. This is followed by concise directions for performing the experiments and the

results of an actual trial. There are many references to the original literature, and, although one wishes the lists were more complete, it is much better than most books in this respect. The diagrammatic drawings given to illustrate the text are largely new.

Being written by one who has actually been over the ground himself, the book points out many of the details of the manipulations that often cause much trouble, but are not mentioned in the original articles. The bock covers a field quite distinct from that of the other laboratory manuals ot optics, and represents the work offered as a twelve weeks course in advanced optics at one of the principal optical laboratories of this country.

A. G. S.

Die optischen Instrumente: *aus "Natur und Geisteswelt," Sammlung wissenschaftlich-gemeinverständlicher Darstellungen*, 88ste Bändchen. Von DR. MORITZ VON ROHR, Leipzig: B. G. Teubner, 1906. Pp. v+130. Bound, M. 1.25.

Dr. von Rohr's book is written in an interesting and popular style, and covers the subject probably as well as any descriptive work can do. The small size of the book and the general plan of the series to which it belongs naturally limit it in scope, but within its limits it is well arranged, and many of the interesting facts of optics are touched on, if not analyzed. First after the discussion of elementary considerations concerning lenses, including the effects of diaphragms variously located, Dr. von Rohr explains the action of the eye as an optical instrument, and states some of the principles governing binocular vision. Other optical instruments Dr. von Rohr divides roughly into objective (those where the lens is used simply to project the image of an object; as in the photographic camera, the stereopticon, and the cinematograph), and subjective (those in which the lenses are arranged and designed expressly for use with the human eye; as in the reading-glass. the telescope, and the microscope).

The various kinds of aberration that may occur in lenses are described, and the various types of lenses are discussed much in the same way as in Dr. von Rohr's larger book on the theory and history of the photographic objective. The historical development of the photographic objective is traced, and when credit is given to the great German opticians for new designs, a special tribute is also paid to the Americans—to Clark for his great refractors and to Brashear for his astrophotographic lenses. Considered in its entirety, Dr. von Rohr's book is well worth reading and, if translated into English, would be used to supplement the textbooks of the classes in physical science throughout the United States.

It is to be regretted that in this work, as in many others, the discussion of the mathematical side of the subject is omitted. A complete work on the theory of lens-design is much needed at the present time. The indifference with which students of optics and designers of optical instruments work through a long trigonometrical calculation to determine the constants of a lens, and the eagerness with which they seize upon and apply the fragmentary articles in the scientific journals giving developments of Abbe's theory of optical invariants, seem to show that there is a growing demand for a handbook containing such tables that the computer can choose as given quantities, the conditions of field or achromatism a lens is to satisfy and be led to its glass, thickness, and curves as quickly and unerringly as the user of a steel company's handbook is led to the selection of material to use in bridge or building design. STANLEY C. REESE.

PITTSBURG, PA.

An Introduction to the Study of Spectrum Analysis. By W. MARSHALL WATTS. London and New York: Longmans, Green & Co., 1904. Pp. 325; with 135 figures and one colored plate.

This small book doubtless grew out of the author's *Index to Spectra*, but it does not displace that useful compilation, although nearly one-half of this work is devoted to a catalogue of spectra. The first impression one gets of the book is that it is decidedly lacking in balance: possibly a sufficient number of topics are treated, but the relative attention devoted to different matters does not commend itself. The book is not in the same class with Baly's *Spectroscopy*, elsewhere reviewed in this number. The 184 pages of descriptive text are subdivided into 14 chapters. The illustrations are for the most part good, many are quite familiar, and but few are original. Some cannot be regarded as exactly called for in a work treating of spectroscopy—for instance, several pictures of comets, of nebulæ, and of the nebulosity about *Nova Persei*. The book contains no mathematics, a respect in which it may perhaps the better suit the general reader. The principal sections are as follows: "How to Produce a Spectrum;" "Flame-Spectra;" "Spectra Produced by Means of Electricity;" "Absorption Spectra—Electric Arc" (the reason for the juxtaposition is not obvious); "The Diffraction Spectrum—Measurement of Wave-Lengths;" "On the Production of Dark Lines by Absorption—The Fraunhofer Lines of the Solar Spectrum." Celestial objects are treated in about 50 pages. The concave grating is described quite inadequately. The numerical relationships in wave-lengths in spectra are treated at some length. It is not clear here why the author included in the spectrum of hydrogen a number of the brighter

lines of the so-called second spectrum. Spectral relationships have not as yet been given for these, and the author's purpose would have been subserved if the others had been omitted or collected together by themselves. Band spectra, the spectroheliograph, the Zeeman effect, and the Michelson echelon are briefly discussed.

The catalogue of spectra gives the wave-lengths of certain lines for most of the elements, but no explanation is made of the source from which they are derived, or of the principle on which the fainter lines are omitted. A comparison with the author's *Index* shows that the wave-lengths are rounded off from values there assembled. The omission of some explanatory paragraphs in regard to this catalogue of spectra is certainly surprising. The table gives in three columns the wave-lengths, to only the first decimal of the tenth-meter, and numerical data as to intensity in character in the arc and spark, though it is not stated on what scale the intensities are assigned. In many cases a numeral is given in parenthesis under the wave-length. Comparison with the *Index* indicates that this denotes the number of lines omitted between that and the following line. If compactness of the tables had been any object, nearly one-half of the space could have been saved by putting these parenthetical data in a separate column.

An appendix reprints papers by Sir William and Lady Huggins on the relative behavior of the H and K lines, and on modifications of the magnesium line at λ 4481 under different laboratory conditions. It is to be hoped that the author's wish may be fulfilled, that the book may prove a useful guide to "those who have only the simplest means;" it is hardly expected that the work will be of large value to those whose libraries contain the technical works on spectroscopy. E. B. F.

Handbuch der geographischen Ortsbestimmung für Geographen und Forschungsreisende. Von ADOLF MARCUSE. Braunschweig: Friedrich Vieweg und Sohn, 1905. Pp. x+341; 54 figures and 2 star charts. Bound, M. 12.

This book is intended primarily for the use of explorers who may desire to ascertain their geographical position on the earth by means of astronomical observations. We should, therefore, expect to find an extremely simple and brief explanation of elementary principles in spherical and practical astronomy, together with an ample collection of auxiliary tables. But it does not appear that the author has presented his material in an unusually attractive or otherwise novel form, nor has he appended any tables except an abbreviated one for the so-called "Mercator functions." We should have expected to find, for instance, specimen parts of the important ephe-

meris pages printed in the book, with illustrative examples of time and latitude computations for which the ephemeris quantities were taken from these specimen pages.

We shall not consider the volume with much detail from the above rather uninteresting point of view, however, because an English-speaking reviewer is likely to be rendered hypercritical by the great excellence of our existing treatises on practical astronomy. But surely we might expect this volume to give prominent space to the measurement of geographical position in exceptional cases of unusual difficulty not considered in previous textbooks. For instance, why do we not find an example, completely worked out, of a latitude determination near the pole? How did Nansen make sure he was "farthest north"? He must have observed the arctic Sun when its altitude changed but little in many hours, and when stars were altogether invisible. Nansen's actual observations under these circumstances would be of great interest, and would have been in their proper place as an example in this work.

Again, for azimuth, the author advises observations of *Polaris* in the northern hemisphere, and of certain less favorable polar stars in the southern. How about travelers in the equatorial regions, where no polars can be observed on account of proximity to the horizon? How are ordinary meridian altitudes observed when the Sun's declination at noon is almost equal to the latitude, when for a number of minutes no one can tell within a quadrant or two which point of the horizon is under the Sun?

The book contains many such things. There is a chapter on observing with strings and stones, in case all angle-measuring instruments should be lost; but there is no mention of the method of measuring latitude by the duration of sunrise. This last method can even be used without any ephemeris. On page 241 there is a sextant example of which the venerable observations were made in 1808, yet this book is surely the most modern treatise on the very latest thing in astronomy—balloon navigation. The instrument used in measuring altitudes from the car is a modification of Abney's level, the angle being read from a quadrant after bringing the Sun, seen through a small telescope, into coincidence with the reflection of a level bubble. Reductions are made by means of Sumner lines, and the results of a number of actual observations are given. We strongly suspect, however, that the navigating officer of the good balloon "Brandenburg" reduced his observations after the vessel had not only been anchored, but actually folded up and laid away after letting out her gas.

We recommend this volume to the librarians of all well-equipped balloons. J.

ERRATA

In the January number Fig. 2 of Plate IV, illustrating the article by Messrs. Hale and Adams, should be inverted. As printed, the end of longer wave-lengths is on the left-hand side instead of the right-hand side as indicated by the legend.

The legend under Fig. 1 of Plate V should read "Region λ 5150—λ5230" instead of "Region λ5150—λ5270."

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THE SPECTRUM OF HYDROGEN IN THE REGION OF EXTREMELY SHORT WAVE-LENGTH

By THEODORE LYMAN

In a preliminary paper[1] the author has given the wave-lengths of more than 130 lines in the region of the spectrum lying between the values 1850 and 1030 tenth-meters. It is the object of the present paper to compare the results obtained by the author with those given by Schumann, to describe the apparatus used in this research, and to call attention to some new facts which have come to light since the publication of the first notice. The description has been made with some minuteness in the hope that an exact knowledge of the conditions necessary to success may prove of value to investigators who work in this field. Some attention has also been given to earlier and imperfect forms of the apparatus. For the author wishes, by flagging the pits into which he has fallen, to prevent other investigators from similar accidents.

The improvements over the method of Schumann which characterize this research consist in the introduction of a concave diffraction grating in place of fluorite prism and lenses, thus permitting the measurement of wave-lengths. The object of continuing the work has been to improve the accuracy of the measurements and to eliminate from the radiation obtained from a hydrogen tube those frequencies which were due to impurities.

[1] *Astrophysical Journal*, **19**, 263, 1904.

As it is unsafe to rely upon a process of extrapolation even with a grating spectrum, the two-slit method described in a previous paper[1] was employed. The spectroscope has been altered in construction to permit of all the adjustments required for this method, and finally the photographic plate itself has been bent to agree in curvature with the arc of the circle on which the spectrum is in theory formed. Very considerable increase in accuracy has thus been gained. The grating with which the work has been done possesses one extremely strong first spectrum; in fact, it is to its brilliancy that the success of the research is due. In spite of the feebleness of the other spectra, however, it has been found possible to obtain many of the stronger lines between λ 1550 and λ 1250 in the second spectrum. Their measurement therefore forms a valuable check on the numbers obtained by the two-slit method.

The elimination of the lines due to impurities from the spectrum of hydrogen necessitates the study of the spectrum of air. As has been set forth in the earlier paper, it is found most convenient to fill the spectroscope itself with pure hydrogen; in fact, if the lines of the shortest wave-length are to be obtained, the light-path must be entirely in this medium. No window between discharge tube and spectroscope is permissible. When, however, the spectrum of a gas other than hydrogen is to be studied, a window of fluorite must separate the discharge tube from the spectroscope. The extent of the spectrum is therefore limited by the transparency of colorless fluorite; and the absorption of this substance has formed a necessary part of this research. As a matter of fact, even fluorite of the best quality was found to absorb all light beyond wave-length λ 1200; the study of the spectra of gases other than hydrogen therefore terminates with this value.

In view of the fact that Schumann made use of two fluorite lenses and a fluorite prism, it seemed extremely probable that his spectrum does not extend beyond wave-length λ 1200. To test the matter, the plates published in the *Smithsonian Contributions to Knowledge*, No. 1413, have been compared with the normal spectrum obtained during this research, and it has been found possible to identify a great majority of the hydrogen lines in this prism spectrum with lines measured

[1] *Physical Review*, **16**, 257, 1903.

by the author. Two important results follow. First, a scale of wave-lengths has been attached to the Schumann spectrum, as shown in the half-tone reproductions at the end of this memoir. Second, since the line of lowest wave-length visible in Schumann's plates has the value λ 1267, the present limit, λ 1030, establishes a considerable extension of the spectrum.

Since the effect of change in the electrical conditions under which a spectrum is produced is extremely important, the question of the existence of a secondary spectrum of hydrogen in the region of short wave-lengths has been examined. No such spectrum appears to exist; that is to say, there is but one hydrogen spectrum between λ 2000 and λ 1200.

The following pages contain a detailed account of the work of which the foregoing paragraphs may serve as an outline.

THE SPECTROSCOPE

The apparatus consists of two parts, the spectroscope itself and the vacuum receiver in which it is inclosed. The spectroscope is formed of a drawn brass tube 9.1 cm in internal diameter, 96 cm long, and 1.5 mm thick, one end of which is provided with an arrangement for holding the grating, while the other end carries the plate-holder and slits. The grating mounting consists of a square brass plate pivoted to turn about a vertical axis. The grating is held against this plate by springs, while screws through the back of the plate permit of the necessary adjustment about a horizontal axis.

At the end not occupied by the grating a draw-tube fits into the large tube. Upon the end of this draw-tube are mounted the slits and plate-holder in a manner shown in Figs. 1, 2, and 3, which may be described as follows: A circular brass disk closes the end of the draw-tube and is pivoted about the points *A A* (Fig. 3). The motion of this disk is regulated by the screws *X X*. Upon the disk are mounted the two slits *S S*. The width of the slits is controlled by the usual screw adjustment. In order to be able to adjust the slits parallel to each other, one of them is mounted in a tube which turns in the disk, the amount of this twist being regulated by the lever *L*.

The plate-holder *C* is so constructed that several photographs may be taken without withdrawing it from the apparatus. To this end the

disk carries two ways, *D D*, in which the plate-holder slides. The position of the holder in the ways is controlled by the lever *E*, pivoted about the point *F*. One end of this lever carries the pin *G*, while the other end is provided with an iron armature *H*. The pin *G* engages

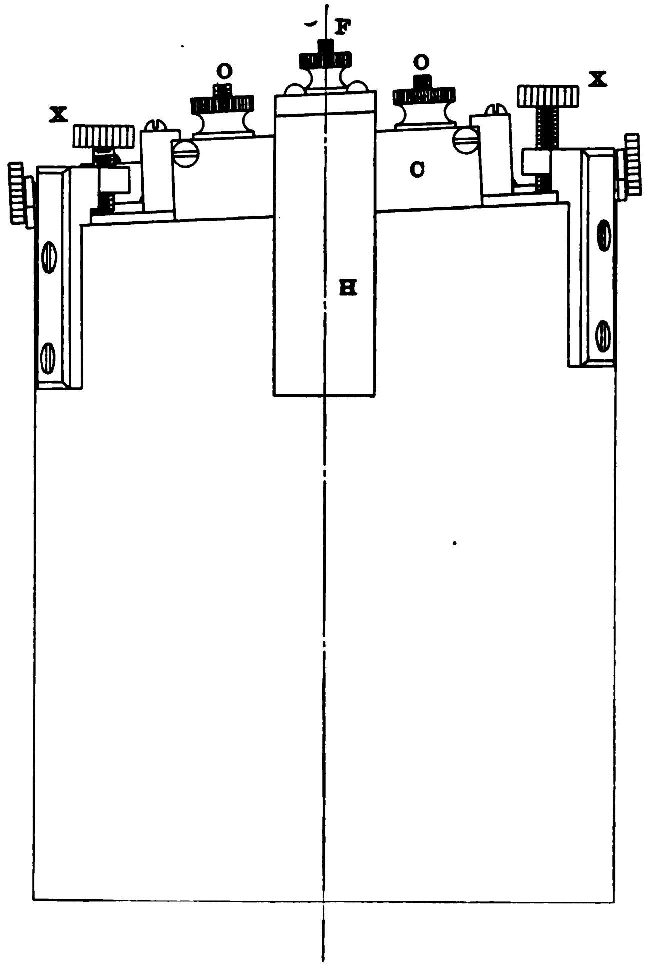


FIG. 1

one of the horizontal rods, *I*, and thus holds the plate-holder in position. To shift this position it is only necessary to swing the lever about *F* by means of a magnet exterior to the apparatus; the pin *G* then slips past one of the rods, *I*, and the plate-holder falls by an

amount corresponding to the distance between two rods. The plate-holder is designed to permit the plate to be bent to the arc of a circle of given curvature. To this end it is constructed in two parts, the outside case *C* and the movable form *M*. The form (shown with-

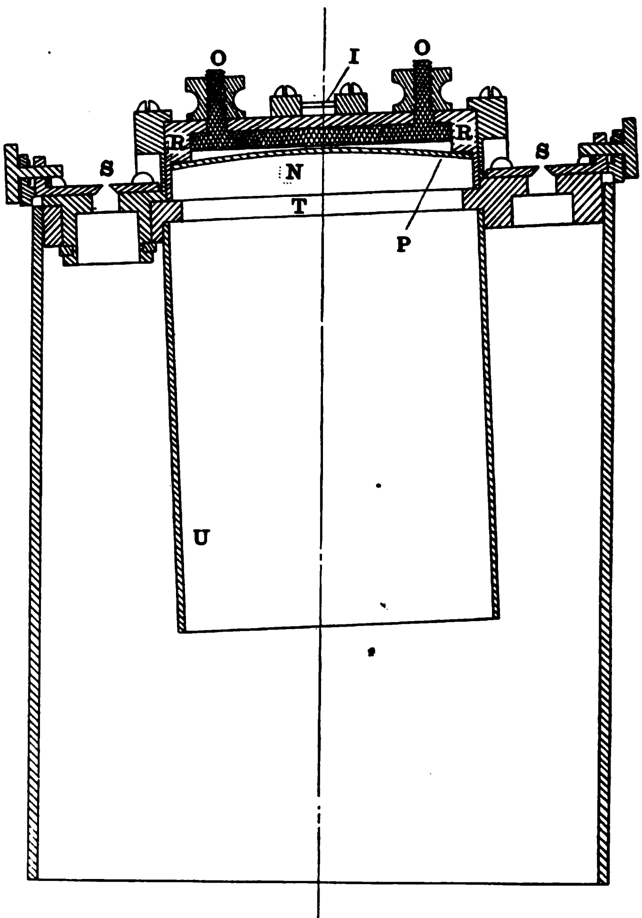


FIG. 2

drawn from the case, Fig. 4) carries two strips, *N N*, whose under sides are cut to the desired curvature; the ends of these strips project beyond the main body of the form. The plate *P* is slipped into the form and is tangent, when unbent, to the curved strips at their middle

point. The form is then drawn into the case by means of the screws *O O*, the ends of the plate come up against the shoulders *R R*, and as the screws are tightened the plate is bent to coincide with the strips *N N*.

The apparatus is so constructed that the curve to which the plate is bent passes through the slits. Light has access to the plate through

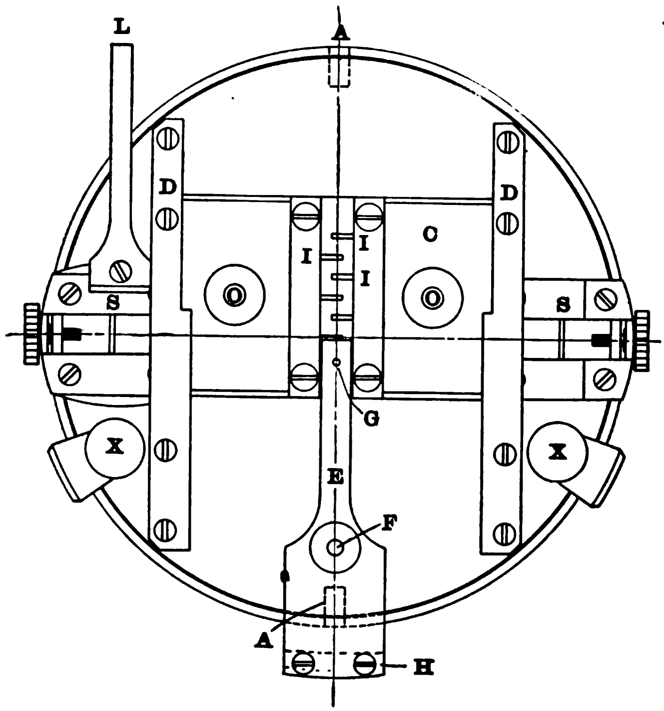


FIG. 3

a slot *T* cut in the disk, which slot also serves as a diaphragm for the spectrum. A sleeve, *U*, shields the plate from scattered light; and to reduce the reflection from the walls of the tube a set of circular diaphragms is provided. The whole system, draw-tube and large tube, is blackened inside by the usual process. In the early work it was proposed to inclose the spectroscope as above described in a large glass tube, but, owing to the difficulty of closing such a receiver air-tight, and owing to the great liability of tubes of this size to break, the

plan was abandoned. The receiver at present in use consists of a drawn brass tube 11.3 cm in diameter, 110 cm long and 1.8 mm thick. It is provided with two flanges, one at each end, cut from sheet brass and soldered to the tube. The flange at the end destined to be nearest the grating is closed by a circular brass plate, ground true, some 17 cm in diameter. Plates of two kinds have been used to close the other end of the receiver. In the simple form shown in Fig. 5, a circular brass disk was pierced only by the two holes destined to admit light to the slits of the spectroscope. In the more complex form, Fig. 7, a hand-hole is also provided through which the plate-holder may be introduced. This hole is 6.2 cm in diameter and is closed air-tight by a conical plug. In order to give this plug a sufficient bearing,

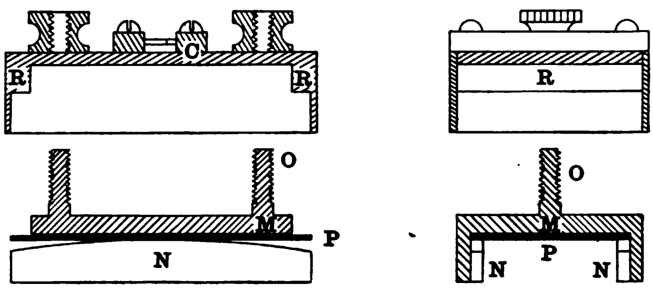


FIG. 4

a sleeve some 4.5 cm high is attached to the face plate. An inlet tube inserted about midway down the length of the receiver serves to exhaust the air; a wooden frame holds the apparatus horizontal. To facilitate the handling and development of the dry plates, the end of the receiver is inserted in a small dark-room. Fig. 6, shows the appearance of this arrangement. Into the receiver thus described the spectroscope is slipped, and small hard-rubber legs hold it in a central position. Fig. 8 shows the end of the apparatus with the face-plate removed.

The concave grating with which the work has been done was ruled in 1903 on the improved engine at Johns Hopkins University. The material is the usual speculum metal, the radius 97 cm, there are 15,028 lines to the inch. The diamond point was selected with the object of throwing as much of the light as possible into one spectrum.

To the great success which attended this effort the results of the work are due, for the instrument possesses one first spectrum of extreme brilliancy.

As the experiment is carried on in an atmosphere of hydrogen, the preparation of the gas forms an important factor. Zinc and hydrochloric acid of the greatest commercial purity obtainable are used. The gas is passed over potassium hydrate and collected over distilled water. Before the gas is admitted to the spectroscope it is dried over calcium chloride and phosphorous pentoxide. The drying tubes are protected at each end by a stopcock; thus the gas does not flow through the system directly, but stands over the material for some minutes before entering the spectroscope. The perfect dryness of the gas is necessary for the success of the work. All connections between hydrogen apparatus, tubes, and spectroscope are of glass. The evacuation is effected by a Geryk oil-pump driven by an electric motor, and the pressure is read by a McLeod gauge properly protected by drying-tubes. Here again all connections are of glass. All air admitted to the spectroscope is passed through a separate set of drying-tubes. This precaution has been found necessary to prevent the appearance of absorption bands. The joint between the brass receiver and the system of glass tubing is effected by a glass sleeve made tight with De Khotinski cement. Though this form of joint leaves something to be desired, nothing better has as yet been devised.

Fig. 5

The use of a discharge tube separated from the receiver by a fluorite window necessitates a separate pumping system, for the tube

must be exhausted apart from the receiver and filled with the gas to be studied. For this purpose a mercury pump by Kiss of Budapest has been used. The hydrogen is made electrolytically from a solution of barium hydrate and is dried over phosphorous pentoxide.

The form of the discharge tube depends upon the manner of making the experiment. If the tube is to communicate directly with the

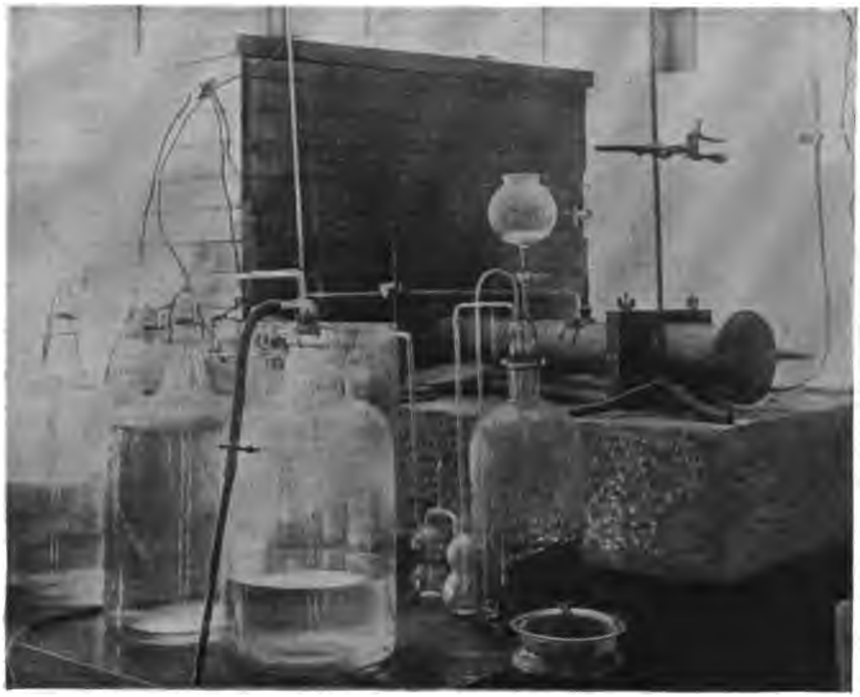


FIG. 6

receiver, so that the whole apparatus is filled from the receiver with hydrogen, the usual form of capillary tube with ring electrodes is employed. The dimensions in a typical case were as follows: length of capillary 6.4 cm, internal diameter 2.5 mm, diameter of electrodes 1.6 cm, distance of mouth of tube to electrode 4.5 cm. This last dimension is of special importance, since, if it be made too small, the discharge from the tube spreads into the receiver and produces fog, and if it be made too large, intensity of illumination is sacrificed.

If the tube is to be separated from the receiver by a window, and is to be separately exhausted, a special form is used (Fig. 9). Here the end of the internal capillary is brought as near the fluorite window as may be without undue heating. A device of this type not only brings the source of light near to the slit of the spectroscope, but reduces the absorption in the tube itself to a minimum. The last advantage is a most important one in dealing with gases such as air which absorb strongly. The electrodes in both forms of tube were usually of aluminium, but iron and copper have also been tried.

FIG. 7

ADJUSTMENT

After the spectroscope is placed in the receiver, the grating is turned until that part of the first spectrum to be investigated falls on the photographic plate. The arrangement of two slits serves a double purpose, as by it either the method of shifted spectra or the second spectrum comparison method may be used without altering the position of the grating. For no matter which method is to be employed, the grating is so placed that light from the right-hand slit gives the region of short wave-length in the first spectrum, while by illuminating the left-hand slit a shifted first spectrum is obtained superposed upon a shifted second spectrum. The dimensions of the apparatus are such that when the longest wave-length which falls on the plate from the ight-hand slit lies in the region of λ 1900, the longest wave-length in the shifted first spectrum has a value of about λ 3100. Observation of lines in the shifted spectrum serves therefore as a simple test of the exact position of the grating. When this position has once been reached, the grating end of the receiver is closed, a very little vaseline

being used in the joint, and the edge is luted with shellac or De Khotinski cement of the softer kind. It next becomes necessary to prepare the other face-plate. If the shifted spectrum method is to be employed this process consists in covering that hole which is to admit light to the left-hand slit with a quartz window, and to seal the discharge-tube over the right-hand opening. This last adjustment is a tedious one, for the mouth of the discharge-tube must be ground at such an angle that the capillary lies in the line determined by the slit and the grating center. This can be done only by trial. When the correct angle has been arrived at, the tube is fastened to the face-plate with De Khotinski cement. To insure a strong joint, the brass surface must be heated during the operation. The face-plate with the tube thus attached is rubbed evenly with a little white vaseline and applied to the flange of the receiver. Here great care must of course be used that the tube is in line with the slit. To facilitate this operation, tubes of both forms are made double-ended, that is, they have a quartz window by means of which it is possible to look through the capillary to the slit and thus assure correct alignment. Once in position, the plate is clamped and the edge luted with cement. Fig. 7, illustrates the appearance of the more improved form of plate and discharge-tube in position.

FIG. 8

The fact that the end of the receiver is in a dark closet permits the plate-holder to be placed in the ways of the spectroscope through the hand-hole without danger of fog. The hand-hole is next closed by the conical plug, and around the edge of the joint a little shellac is spread. The apparatus is now ready to exhaust. If no window is used between discharge-tube and spectroscope, both parts of the ap-

paratus are of course exhausted together and both are filled with hydrogen together. If a window separates the two, the tube must be exhausted by the mercury pump and filled from the separate supply of hydrogen. In either case the most laborious part of the adjustment lies still ahead; for the spectra from both slits must be in focus at the same time, and the position of the plate-holder can be determined only by trial. It is therefore necessary to take a series of spectrograms, removing the face-plate after every trial in order to change the adjustment of the spectroscope, and replacing the plate on each occasion air-tight in order to exhaust and fill with hydrogen. As can be easily understood from the figure, in order that the conditions of adjustment should be fulfilled, both slits must lie on the circle whose diameter is the grating's radius of curvature, and the plate must form a part of the arc of this circle. By construction the curve to which the plate is bent passes through the slits. There are then two degrees of freedom of adjustment, the draw-tube can be run in and out, and the disk can be turned about the axis A A; these two motions will suffice to bring the slits and plate into their correct theoretical positions.

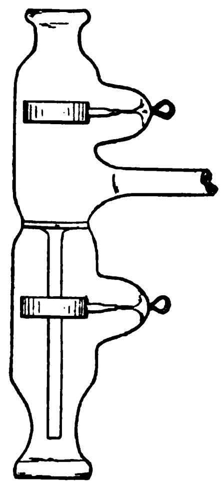


FIG. 9

Tedious as is the method of trial above described, it has seemed better to adopt it rather than to complicate the apparatus by the introduction of devices to regulate the focus from outside the receiver. Such devices might permit the focus to be changed without admitting the air, but the author is not at present prepared to face the problem of moving joints which must be maintained air-tight. Once the spectroscope is in adjustment, the face-plate, if it is of the improved form, can remain permanently in place.

As regards pumping the apparatus, and as to the extent to which it is necessary to wash with hydrogen with a direct connected discharge-tube, the following example may be of interest. The receiver and drying-tubes were first exhausted to 0.7 mm of mercury. The tubes were then shut off and filled with hydrogen; after the gas had stood over the drying material for two or three minutes, it was admitted to

the receiver. A second filling of hydrogen was let into the drying-tubes and in turn run into the receiver. The tubes are of such a capacity that two fillings raise the pressure by about 15 cm of mercury. The pump was then applied and the pressure reduced to 0.45 mm; hydrogen was admitted, the pump again applied until the pressure again reached about 0.45 mm, and an equal amount of hydrogen was for the third time admitted. It was usual to repeat this process of washing at least four times before a photograph was tried.

In making the exposure the end-on tube was excited by the transformer described in the previous paper. For the best results that pressure was chosen which gave a brilliant discharge in the tube without being so low as to permit the glow to spread from the tube into the spectroscope. The best value for the pressure under the conditions was in the neighborhood of 1.5 mm. The receiver was generally pumped to this pressure before the tube was excited.

In a plate such as that previously published where several spectra appear upon one negative, it was usual to allow a fresh supply of hydrogen to enter the receiver between each exposure. Thus after the plate-holder has been lowered by the magnetic device the receiver is re-pumped. It is just to suppose that the gas in the apparatus is much purer during the last exposure than during the first. The effect of this increased purity upon the nature of the spectra themselves has been noted in the former article; unfortunately the reproduction did not show the effect at all well, though it was extremely clear upon the original negative.

The process of washing, pumping, and rewashing is of necessity a tedious one and generally occupied the better part of a day. Schumann has observed that the appearance of the hydrogen spectrum in its visible part was no criterion of its purity as observed in the region of short wave-length. It may be of interest to add, nevertheless, that the discharge-tube when properly washed with hydrogen showed the many-line spectrum of that gas in a state of considerable purity. The appearance of air lines was always a sure warning, if a discharge-tube without a window was used, that the spectrum on the photographic plate would be extremely feeble.

In work of this kind it is found almost impossible to make the receiver absolutely air-tight. In fact, some of the most successful

of the early plates were obtained in the presence of a slight leak. Under the circumstances the magnitude of this leak becomes of importance. For example, the plate of the previous article was obtained with the surprisingly large leak of 0.2 mm in an hour, showing that perfect tightness of the apparatus was not necessary when proper attention was given to washing with hydrogen. If, however, the receiver was to be exhausted below 0.1 mm, the leak must be very much reduced. Practice and care in setting the face plate secured this result, and work has been done where the leak in twenty-four hours was less than 0.02 mm.

In those cases where the discharge tube is separated from the spectroscope by a fluorite window what has been said about the purity of the gas in the receiver and the amount of washing necessary to secure it remains of course true. To this is now added the trouble of pumping and filling the discharge-tube with whatever gas may be under examination. The gas in the discharge-tube, however, may be used over a considerable range of pressure, for the presence of the fluorite window prevents the discharge from spreading into the spectroscope. In practice the pressures varied in different experiments from 2 mm to 0.5 mm. The pressure in the receiver was usually reduced to 0.1 mm, though, if the hydrogen be pure, so low a pressure is not at all necessary. The width of slit used varied from 0.09 mm in the case of the crude plate published in a former article, to about 0.025 mm in the case of the fine plates from which measurements have been made.

The time of exposure for the hydrogen spectrum varies between five and thirty minutes, according to the width of slit and the sensitiveness of the plate.

DRY PLATES

Little can be added to Schumann's description[1] of the manufacture of the special dry plates necessary in this work. The first part of the research was carried on with plates prepared from glass 1.5 to to 2 mm in thickness. When the form of the spectroscope was improved and it became necessary to bend the plates to the arc of a circle, special sheets of thin glass were required. In order that the emulsion may flow evenly the plates must be very flat. This necessity of flatness, together with the mechanical difficulties of grinding,

[1] *Annalen der Physik*, 5, 349, 1901.

put a limit to the thinness of the sheets. In practice plates 8.8×13 cm and between 0.4 and 0.5 mm thick are flowed, and when dry are cut into small pieces 2.6×4.4 cm.

One slight departure from the method of Schumann has been found advisable: each plate was separately supported on legs during the process of flowing. In this way, if the emulsion runs over the edge of one plate, only that plate is spoiled; while if all the plates are on one leveling table, a disaster to one may result in the overflow of all.

In development the author has used ortol with good results. Here, as has been remarked by Schumann, the strength of the developer must be regulated by the age of the plate. The addition of ice is a very necessary part of the process. The following proportions are suitable to plates six months to a year in age: Ortol A, 1 part; B, 2 parts; water, 2 parts; ice, about 1 part.[1]

ELECTRIC APPARATUS

The electric apparatus used to excite the discharge-tube has in almost all cases consisted of a transformer run from the 60 cycle 110-volt alternating circuit and provided with a suitable rheostat in the primary. When such a transformer is used with a discharge-tube containing gas at pressures from 1 to 0.1 mm, the addition of capacity across the terminals of the tube produces—with most gases—very little effect on the nature of the discharge, because the low resistance of the tube, after the current has once begun to pass, does not permit the condensers to charge. If a spark-gap be introduced in series with the tube, this difficulty is of course obviated. In all the earlier work no gap was used, so the spectra obtained were due to a discharge practically without capacity. The capacity when introduced consists of glass plates coated with tin-foil and has a value of perhaps 0.005 microfarads. In some of the work a coil with a mechanical break taking 12 volts and 5 amperes in the primary has been substituted for the transformer. In the case of the metallic spectra used for comparison the spark has of course been brightened by the use of capacity.

[1] A.	Water	1000 c.c.	B.	Water	2000 c.c.
	Metabisulphate of potash	7.5 gr.		Pot. carb.	120 gr.
	Ortol	15 gr.		Sod. sulphite . . .	360 gr.
				Hypo 1 to 20 . . .	20 c.c.

METHOD OF TESTING FLUORITE

In order to provide a window of the greatest possible transparency for the discharge-tube in those cases where the spectra of gases other than hydrogen were to be examined, it was necessary to test various specimens of fluorite which the author had at his disposal. The method was as follows: The piece under trial was attached to the plate-holder at the end of an arm in such a way that it projected to the right of the ways in which the holder moves. The length and shape of the arm were so adjusted that when the plate-holder was at its highest position the fluorite was just above the right-hand slit; but when the holder had been allowed to fall, the fluorite slab fell with it and came between the slit and the mouth of the discharge tube. The receiver was exhausted and filled with hydrogen in the usual way, and a rather wide slit was used. A photograph was then taken with the plate-holder at its highest position, thus the light path lay entirely in hydrogen. Next, by means of the magnetic device, the plate-holder was allowed to fall until the specimen of fluorite came in front of the slit; the light from the tube now passed through the fluorite before reaching the slit. By comparing the two spectra obtained one below the other on the same plate the point in the spectrum at which the specimen cut off the light could be easily determined.

Six circular plates of white fluorite 3 mm thick and 2½ cm in diameter, and two plates 2 mm thick—all from Zeiss of Jena—have been tested, with the result that, while none of them is absolutely opaque to light above λ 1600, their transparency varies very much. In no case, however, was any line of wave-length shorter than λ 1200 obtained, and of the eight pieces but two showed this transparency. The abrupt nature of the absorption at this point is well shown by Spectra 2 and 3 in Plate XI. Spectrum 2 was taken with the internal capillary discharge-tube and fluorite window, and 3 with no window between tube and slit. The author is not, of course, prepared to say that no fluorite does exist transparent to light above λ 1200; he can only say that of the best specimens obtainable up to the present but two show even this limited transparency. The discovery of some substance transparent to light of the very shortest wave-length known to exist would be an important step. For our knowledge of the spectra of gases other than hydrogen is at present limited by the transparency of fluorite.

The effect of the thickness of the fluorite window was tested by taking a series of spectrograms through one of the two best specimens, and then reducing the thickness of the piece from 3 to 0.9 mm. A second series taken through this thinner window showed no extension of the spectrum whatsoever. This is a result which might have been expected from the work of Schumann, and which confirms, for this region, that slow increase of absorption with thickness which has been observed in other parts of the spectrum.

ABSORPTION OF THE AIR

The absorption of the air is the important factor in all investigations which have to do with radiations of short wave-length. Cornu was the first to investigate the matter systematically, but Schumann has vastly extended the work, and has given data on the relation of length of air-path to the limit of the spectrum. His method was to interpose between his source of light and the slit of his spectroscope a cell the thickness of which could be varied. This cell was filled with air at atmospheric pressure.

There is not much to add. The method here employed was as follows: The discharge-tube was separated from the spectroscope by a fluorite window, and spectrograms were taken with air in the receiver. Thus the light from the discharge-tube traversed a layer of fluorite, and then passed through air to the grating and back to the photographic plate—a distance of about 200 cm. By taking a series of spectrograms at different pressures the variation of the absorption with pressure could be observed. At the very beginning of the investigation the author was confronted by a puzzling and persistent phenomenon—the absorption of the air appeared to be selective, not total; for a broad absorption band appeared between λ 1790 and λ 1550, and remained undisturbed even when the pressure had been reduced to 0.17 mm. At this point the air permitted the remainder of the spectrum to pass nearly out to the limit of transparency of the fluorite window. It was only after the receiver had been frequently washed with carefully dried air that the absorption band disappeared. The phenomenon is therefore due to some impurity, possibly something which comes from the brass of which the receiver is made, and which only persistent pumping will remove.

It is not perfectly satisfactory to compare the values obtained by Schumann which are given in terms of the absorption of a column of air at atmospheric pressure with those obtained by the author. It may be of some interest to point out, however, that, if the lengths of two equivalent air-paths are to each other inversely as their corresponding pressures, the column of air in the receiver at 0.17 mm pressure 200 cm long is about equivalent to a column at atmospheric pressure 0.4 mm in length. Now, when the receiver was at this low pressure, light of wave-length a trifle below λ 1400 was recorded on the photographic plate. It appears therefore that a column of air 0.4 mm long will permit light of this short wave-length to pass in sufficient intensity to affect a photographic plate under the conditions of the experiment.

The expression of the absorption of the air in anything like an absolute system is a very difficult matter. The point of practical interest in this part of the research is the advantage of an atmosphere of hydrogen in the receiver. It is not easy to exhaust the apparatus to a sufficient degree of transparency, but by successive washings with hydrogen traces of air can be removed and its absorption very largely eliminated.

PURITY OF THE SPECTRUM

The spectra of hydrogen from which the wave-lengths recorded in the following tables were measured have been obtained under some variety of condition, but they all show considerable uniformity of appearance. The greatest difference occurs between those spectra obtained from an internal capillary discharge-tube closed by a window and those where the tube communicated directly with the receiver. Contrary to expectation, the spectra obtained under the latter condition are much purer than those which the first method yields. No matter with what care the closed discharge-tube is pumped and repeatedly washed with hydrogen, certain characteristic bands are bound to make their appearance to a greater or less degree. The nature of these bands is unfortunately only too clearly seen in Spectrum 2 of Plate XI. If, however, the tube communicates directly with the receiver and is filled with hydrogen along with it, these bands may be totally absent. Schumann has observed their presence and ascribes them to carbon monoxide. On this point the author cannot yet be

sure; certain it is, however, that they occur strongly in the spectrum of the air. (Compare Spectra 1 and 2, Plate XI.)

The means used to produce the hydrogen for the discharge-tube have been varied. Zinc and hydrochloric acid, and electrolytic action on both dilute sulphuric acid and on barium hydrate solution, have served as sources for the gas. Various shapes of discharge-tube have been tried, both closed and communicating directly with the receiver. Aluminium, copper, and iron have been used as the material of the electrodes, which in turn have been of various dimensions. The comparison of the plates taken under the above conditions serves as an excellent test of the true source of the radiations supposed to be due to hydrogen.

In addition, the spectra obtained by exciting the discharge-tube when filled with air at pressure between 2 and 0.5 mm have been compared with the spectra obtained when the same tube was filled with hydrogen. The lines found to be common to the two spectra have been eliminated as due to the air itself or to some impurity. Such a process may result in the loss of a few true hydrogen lines, but what remains can be safely attributed to that gas. Finally, this matter has been checked by a study of the behavior of suspected lines, as the purity of the hydrogen in the discharge-tube is increased. It must be remembered that the elimination of lines due to impurities by comparison of the air and hydrogen spectra can be applied only to those radiations which lie in that region for which fluorite is transparent. The results are to be found in the table of wave-lengths given at the end of this paper.

The general appearance of the spectrum may be described as follows: Between λ 2000 and λ 1675 the author can find no trace of radiation due to hydrogen, but he is not prepared to assert that a faint continuous spectrum may not exist. From λ 1675, however, the spectrum consists of a multitude of very fine lines with a maximum of intensity near λ 1600. Near λ 1300 something very like an absorption band occurs, due perhaps to some slight trace of impurity in the gas, but always present no matter under what conditions the gas may be produced or examined. Lines are visible in this band, but they are very feeble. The lines beyond the region limited by the absorption of fluorite are some of them as strong as any in the spectrum. The

shortest measured wave-length has the value λ 1030, but beyond this there are some very faint lines whose wave-length must be between λ 1000 and λ 1010. At present these lines form the limit of the spectrum.

The nitrogen-like appearance of the spectrum of air shown in Fig. 1, Plate XI, deserves attention. The bands are beautifully clear in the original negative, and their general character can be seen even in the reproduction.

EFFECT OF CAPACITY ON THE SPECTRA

The spectra both of air and hydrogen were obtained with no capacity in circuit with the discharge-tube beyond that afforded by the connections of the apparatus. The effect of capacity on the spectrum of both gases in the visible region is so striking, however, that it seemed worth while to study the phenomenon in this new region of short wave-length. Moreover, the recent attempts which have been made to extract from the change in spectrum with change in condition some evidence as to the nature of the vibrating system of electrons, make such experiments doubly interesting. For in this new region we are dealing with vibrations more than three times as rapid as those studied in the visible spectrum. This difference in rapidity might well be expected to differentiate the effect produced by a given change of condition on the visible spectrum from the effect produced by the same change on the region between λ 2000 and λ 1030. It is even possible to conceive that this differentiation might throw some light on the vibrating system itself.

The research is unfortunately beset with mechanical difficulties. Reference has already been made to the trouble experienced from the spreading of the discharge into the spectroscope and the resulting fog produced on the photographic plate. This difficulty is increased a hundred-fold if a disruptive discharge is sent through the tube, for in this case the whole interior of the spectroscope seems to become luminous, and a total fogging of the plate results. With great care as to regulation of pressure some spectrograms have been obtained, but they have never been perfectly satisfactory, since even if but a single spectrogram is taken on a plate, the time of exposure must be short. When the investigator turns from the direct-connected discharge-tube

to one closed from the receiver by a fluorite plate, he is confronted by a new difficulty. The fog indeed is prevented, but after a short time the violence of the disruptive discharge deposits a thin film on the fluorite window and renders it totally opaque. This film need be hardly noticeable by transmitted light, and yet it will be thick enough to absorb all wave-lengths beyond λ 1800. The material of the electrode exercises of course a pronounced influence, but even with aluminium, which shows the effect the least, the result is as above described. The annoyance of disconnecting the discharge-tube from its pump, removing the face-plate from the receiver, detaching the discharge-tube from the face-plate and cleaning the window, followed by the same set of operations in the inverse order, must be experienced to be thoroughly appreciated. When it is remembered that with a disruptive discharge this process must be gone through after about four exposures, the difficulty of this part of the research will be understood.

In practice the discharge-tube was filled with hydrogen, and a spectrogram taken without capacity; next a spark-gap was introduced in series with the tube, and capacity was put in parallel until the gas showed the four-line spectrum clearly. The appearance of the tube was constantly watched with a direct-vision spectroscope.

A similar set of experiments was tried for air. In both cases the material of the electrodes was altered in various experiments. It is important to observe that the nature of the electrode does not seem to affect the nature of the phenomena.

The effect of the introduction of capacity with hydrogen is to introduce five sets of new lines. These lines lie between λ 1900 and λ 1400; under favorable circumstances they are strong and characteristic. The appearance of the principal spectrum remains unaltered, except for a very slight weakening.

The effect of capacity on the spectrum of air is very different. The band spectrum is weakened to such an extent as to be almost wholly destroyed, and five sets of new lines are introduced. These new or secondary lines are identical with those which appear in hydrogen. Though some of these lines are always present both in hydrogen and in air with the disruptive discharge, they vary very much in intensity from experiment to experiment. This variation with the condition of the research, added to the fact that the secondary lines appear both in

hydrogen and in air, makes it almost certain that they owe their origin to some impurity common to both gases. The nature of this impurity can be decided only after the spectra of the other principal gases have been examined. At present it seems safe to state (1) that there is no secondary spectrum of hydrogen in the region above λ 2000; (2) that the introduction of capacity almost totally destroys even the primary spectrum of air; (3) that new and characteristic lines do come into existence, in both air and hydrogen, and that these lines are probably due to some impurity. In weighing the evidence here presented it must be remembered that these results have been checked by experiments performed under very varying conditions. The pressure and purity of the gases, the shape and character of the discharge-tube, the material of the electrodes, and the time of exposure are all factors which have undergone investigation.

METHODS OF MEASUREMENT

The methods used were two in number. The values of all the lines were first obtained by the two-slit method, and these values were then checked by obtaining the stronger lines in the second spectrum and comparing their positions with known iron lines in the first spectrum. For this last purpose the first and second spectra obtained from the left-hand slit were employed.

The two-slit method has been described elsewhere, but a brief account of its theory and its limitations may not be out of place here. If two slits, S and S', be placed on that circle whose diameter is the grating's radius of curvature, the illumination of these slits by white light will give rise to the images I and I' (Fig. 10). To each of these images a set of spectra will correspond. For the present purpose it is sufficient to concentrate the attention on the two first spectra. It is evident that these two spectra will be shifted with respect to each other by an amount depending on the distance between the slits. If a photographic plate be placed between S and S', and if the height of these slits be properly adjusted, one of these spectra will be superposed upon the other. At a given point, P on the plate, the light brought to focus from S will be of a shorter wave-length than that from S'. If the sources of light be so selected that wave-lengths in both spectra arriving at P have known values, then the shift of one spectrum with respect

to the other may be determined by comparison of these values. If the apparatus is in adjustment, both spectra are in focus upon the same circle, and the amount by which one spectrum is shifted over the other is a constant quantity; that is to say, if the shift is determined by comparing known lines at one end of the plate, it must have the same value at the other end. It is upon this property that success in the use of method depends.

It next becomes of importance to inquire to what extent small errors of adjustment will influence the constancy of the shift. Here the nature of the method upon which the observer must rely in determining the perfection of this adjustment must be remembered. The only practical test consists in the sharpness of focus of the two spectra. It is the object, then, so to manage matters that both spectra shall be in perfect focus throughout the plate's length and at the same time. The vital question at once suggests itself: Is this test sufficiently delicate for the present purpose? If very accurate results are required, the question must be answered in the negative. A little consideration makes it obvious that the relative position of the images I and I', and hence the shift, changes with the focus more rapidly than can usually be detected by the change in sharpness of the lines. In other words, if the shift were given, the proper focus could be accurately determined, but if the sharpness of focus must be relied on, then the true shift can be only approximately inferred. Or again, for practical purposes, the apparent shift varies slightly more rapidly with variation in adjustment than does the sharpness of the spectral lines. The foregoing is of course somewhat dependent on the manner in which the adjustment is made. In the apparatus in question the slits and the photographic plate are rigidly fixed on the arc of a circle. This arc is capable of being thrust in or out parallel to

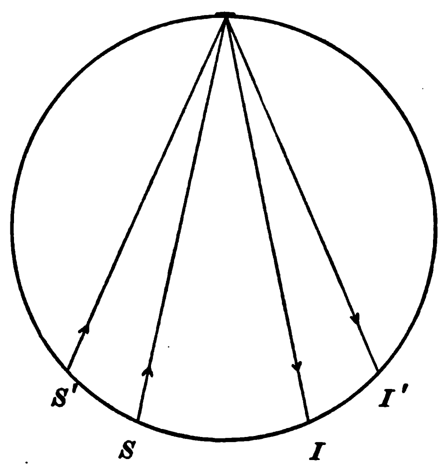


FIG. 10

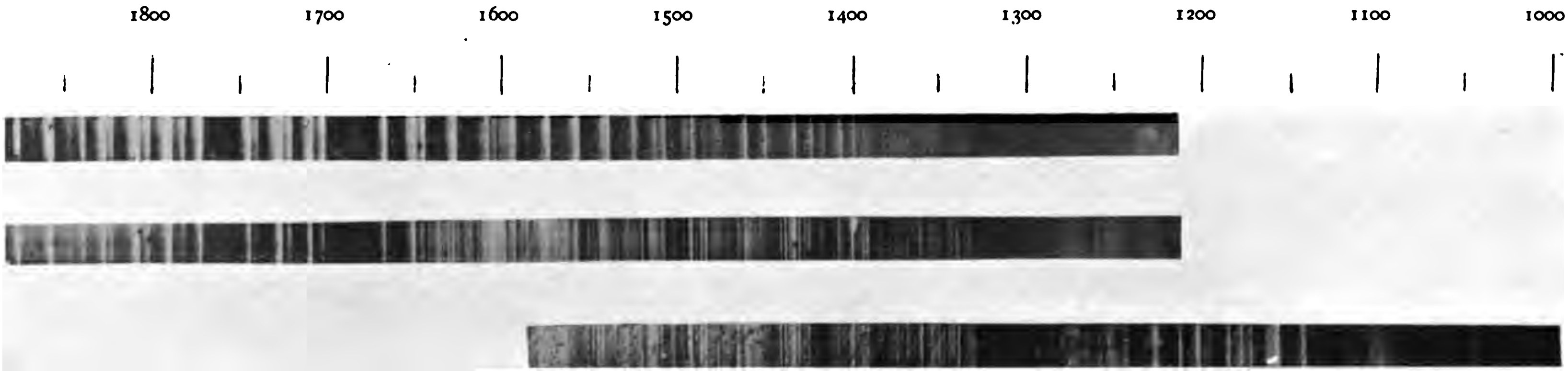
itself along a line connecting the center of the grating and the center of the photographic plate; it is also capable of rotation about its middle point. By these two movements perfect adjustment can be attained, but the test of this adjustment is not absolutely adequate.

The practical application of the method is as follows: The spectrum of iron was selected for comparison work. The grating was so turned that known lines in the spectrum of aluminium fell upon one end of the plate when the right-hand or direct slit was illuminated by light from a spark between terminals of the metal. The shift of the principal spectrum with respect to the comparison spectrum was then determined by comparing the positions of these lines in aluminium with known lines in the spectrum of iron. In order to insure accuracy, this shift determination was recorded on the same plate as the spectrum of hydrogen whose lines were to be measured. This was conveniently brought about by admitting the light from the aluminium spark directly through the discharge-tube, for which purpose the tube was fitted with a window of quartz at the end not attached to the face-plate. Upon the spectrum to be measured was superposed the comparison spectrum of iron, and in this spectrum fiducial lines were selected. The relative value of these lines was then obtained by subtracting the shift from their real value, previously corrected to vacuum. These relative values were then used as points of departure to determine the wave-lengths of the unknown gas spectrum. In practice the shift was 1180 Ångström units, so that the point in the iron spectrum falling on say $\lambda 1400$ of the gas spectrum has a value of $1400 + 1180 = \lambda 2580$.

Owing to the dimensions of the plate a region of only about 760 tenth-meters can be photographed at one time. Thus if the aluminium line $\lambda 1935.29$ falls upon one extreme of the plate, the other end corresponds to wave-length $\lambda 1175$. In order to investigate light of shorter wave-length than this value, it is necessary to turn the grating, a process which necessitates a slight change in the adjustment of slits and plate.

To check the values obtained in the above manner, lines of short wave-length were obtained in the second spectrum. For this purpose the left-hand slit was covered by a discharge tube without a window, and the whole apparatus was filled with hydrogen exactly as usual.

PLATE XI



1. Air

2. Hydrogen and Air

3. Hydrogen

ABSORPTION OF FLUORITE

The two upper spectra were taken through fluorite

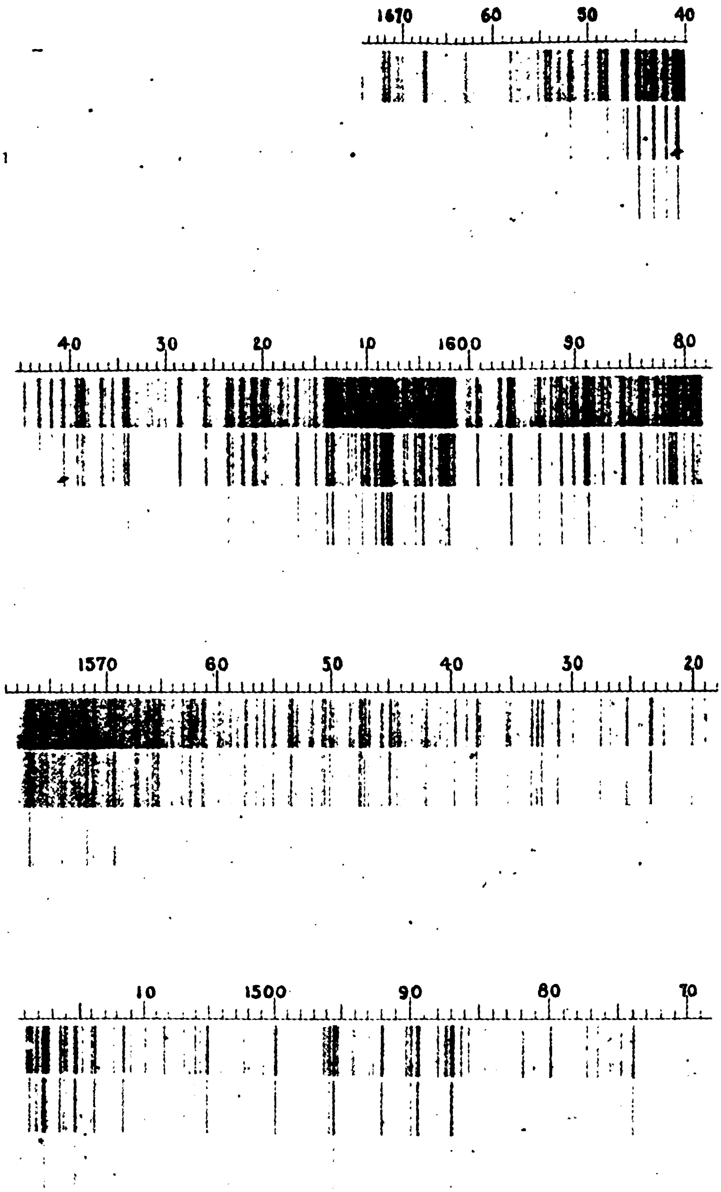
PLATE XII

1

2

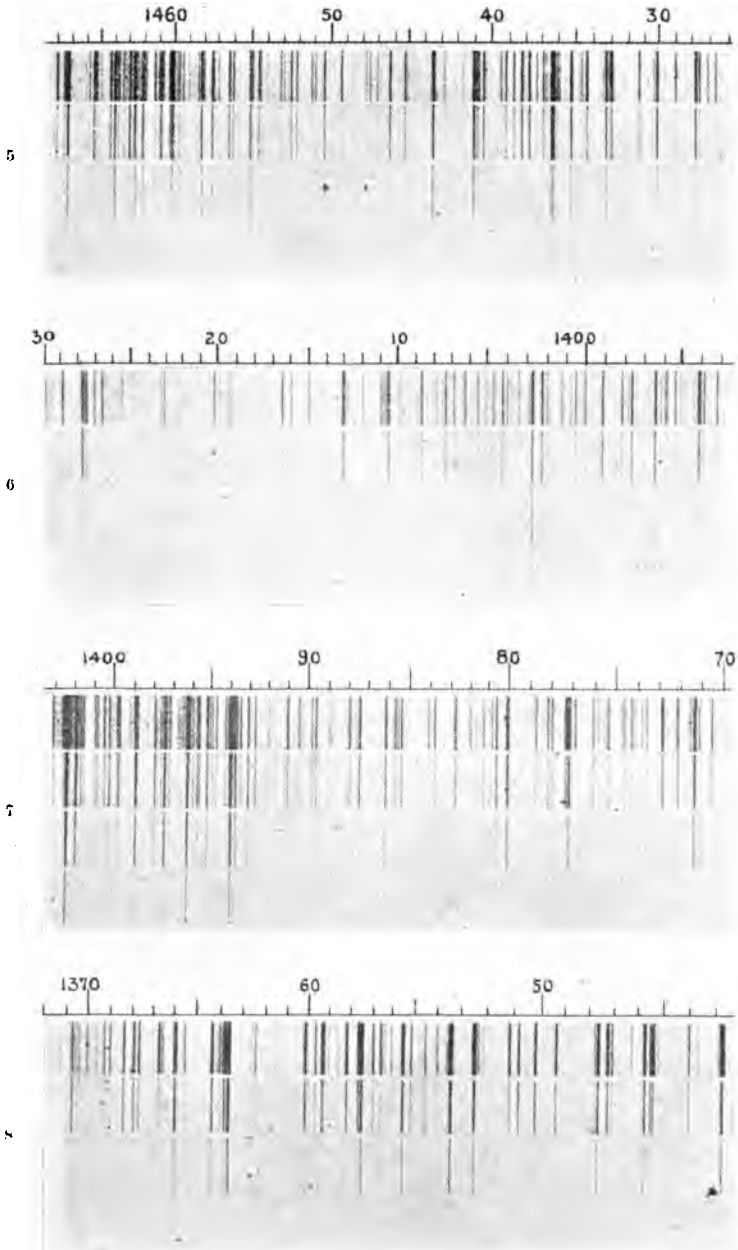
3

4



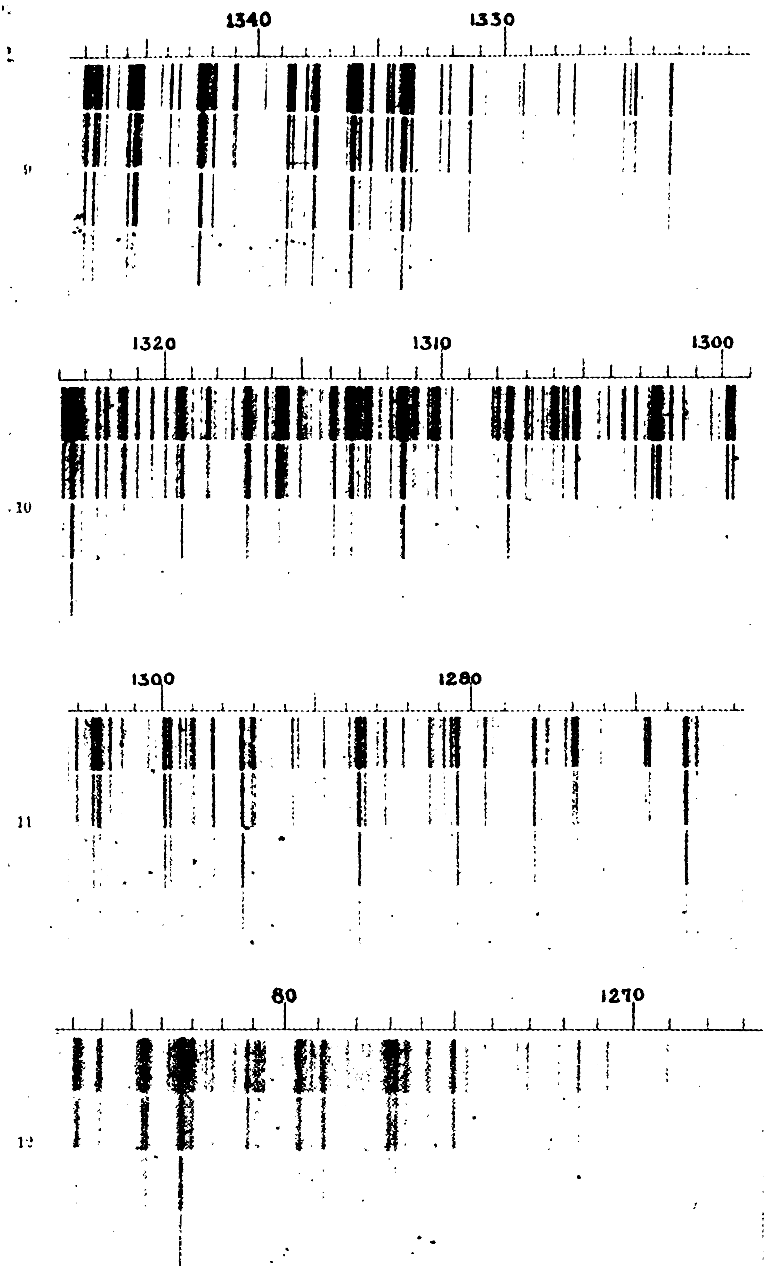
HYDROGEN SPECTRA 1–4.

PLATE XIII



Hydrogen Spectra 5–8

PLATE XIV



Owing to the feeble character of the second spectrum, only the stronger lines between λ1550 and λ1250 could be photographed. Their position was determined by comparison with first-spectrum iron lines obtained from light which had passed directly through the discharge tube.

The plates have been measured on an engine made by Wolz of Bonn after the design by Kayser. The screw has been calibrated and proves to be of an accuracy far greater than this work demands. The intensities of the lines have been estimated, first, by observations made under the reading microscope, and, second, by projecting the spectrum on a screen. The latter method has the advantage that the whole spectrum is before the observer at one time. The values were estimated from plates taken without a fluorite window. The tables are divided into two parts. In the first are given 310 lines lying in that region from which it has been possible to eliminate the lines due to impurities. The error should not be greater than 0.3 Ångström units. In the second are lines in that region beyond the transparency of fluorite; their origin is not absolutely known, but they are probably due to hydrogen, since they were obtained when the discharge-tube was connected directly with the spectroscope, a condition under which air lines rarely occur. The error in these values should not be greater than one unit. The values of the iron lines are from the measurements of Exner and Haschek as given in Watts' tables;[1] the correction to vacuum come from the same source. The wave-lengths of the aluminium lines are from the measurements of Eder and Valenta.[2] The agreement between the tables and the numbers given in the "Preliminary Measurements" is well within the accuracy claimed for the earlier values.

SCHUMANN'S SPECTRUM

In order to compare the prismatic spectrum obtained by Schumann with the values of the table, the twelve plates published in the Smithsonian Memoir[3] were cut out and pasted together. The resulting spectrum, some 127 cm long, was placed upon a movable stand, and the grating spectrum was projected upon it by means of a lens. By changing the magnification so as to keep step with the dispersion, the

[1] W. M. Watts, *Index of Spectra*, Appendix J.

[2] *Beiträge zur Photochemie*, p. 388.

[3] *Smithsonian Contributions*, No. 1413.

strong lines in the one spectrum were identified with those in the other from λ 1674 to λ 1269 without the least difficulty. From the values thus obtained interpolation curves were drawn for each one of the twelve plates separately, and by means of these curves a scale of Ångström units was attached to each of the twelve illustrations. By the permission of Dr. Schumann, and through the kindness of Professor Langley, of the Smithsonian Institution, the half-tone reproductions, Plates XII, XIII, XIV, which accompany this paper were then made from these illustrations. They by no means do justice to the fine originals, but, considering the difficulty of the process, they may be considered fairly satisfactory.

The agreement between the author's measured values and the prismatic lines is extremely gratifying. Of the 285 lines given in the tables, all but three or four are found in Schumann's plates. There are, however, a considerable number of fainter lines in the prismatic spectrum not visible in the plates obtained with the grating. Moreover, owing to the fineness of the slit, and the great dispersion used by Schumann, some of the single lines of the table are seen, by comparison with the prismatic spectrum, to consist of doublets or triplets.

The excellent agreement between these two spectra obtained under such different conditions makes the existence of any chance impurity very improbable.

The extreme line in Schumann's map has the value λ 1266.9. That author has stated that he obtained some lines too faint to reproduce; from the angles given[1] it is difficult to calculate their exact wavelength, but it seems improbable that they should have a value much below λ 1230. In this connection it is interesting to note that the calculation of Martins[2] from the Ketteler-Helmholtz formula for fluorite was not far wrong.

LIMIT OF THE SPECTRUM

It may well be asked: To what is the present limit of the spectrum due? There are several causes which go to make up an answer to this question.

A much longer exposure might result in the discovery of new lines; unluckily there are difficulties in the way of this seemingly simple step; for, as has been previously stated, with a windowless tube there is a

[1] *Smithsonian Contributions*, No. 1413, p. 24.

[2] *Ann. der Physik*, **6**, 619, 1901.

great tendency for the discharge to spread into the receiver and cause fatal fogging of the plate. No plan has so far been devised to obviate this difficulty, and up to the present the length of exposure has been limited by it. Besides this mechanical difficulty, several other possible agents may exert an influence. Speculum metal may cease to reflect in the region near λ 1000; that it reflects so well as far as this point is surprising. The Schumann plates may cease to be sensitive. Small impurities in the hydrogen may exercise considerable absorption. Only experiments on metallic reflection, on the manufacture of plates, and on the purification of gases can answer these questions. The author sees no insurmountable difficulty, however, to the still further extension of the spectrum.

RESULTS

The results arrived at in this paper may be set forth as follows:

1. The spectrum has been extended from the limit obtained by Schumann to the value λ 1030.

2. The lines in the spectrum of hydrogen have been measured accurately from λ 2000 to λ 1228, and the values of the principal lines to λ 1030 have been determined.

3. The nature of the spectrum of air has been investigated.

4. The limit of transparency of certain specimens of white fluorite has been obtained.

5. The effect of the disruptive discharge on the spectra of hydrogen and air has been studied, and the absence of a secondary spectrum of hydrogen established in the region beyond λ 2000.

6. Wave-lengths have been attached to the spectrograms obtained by Schumann.

Much of this research has been carried on with the help of a grant from the Bache fund. The permission to reproduce the plates from the *Smithsonian Contributions* is due to the kindness of the secretary of that institution.

It is impossible to conclude this paper without some tribute to the man whose name will be always associated with the region of short wave-lengths which he discovered, and it is with the greatest pleasure that the author acknowledges the help and inspiration he has received from the friendship of Dr. Victor Schumann.

Jefferson Physical Laboratory,
Harvard University,
December 27, 1905.

Spectrum of Hydrogen Measured by a Diffraction Grating

Wave-Length	Intensity	Character	Wave-Length	Intensity	Character	Wave-Length	Intensity	Character
1228.3	8		1312.9	2		1386.3	3	
1230.1	8		1314.7	1		1387.7	4	
1231.0	1		1315.6	1	double	1390.0	1	double
1232.1	5		1319.2	4		1391.2	1	
1234.3	4		1323.4	5		1393.2	3	
1235.8	6		1325.0	5	double	1394.0	7	double
1239.6	3		1327.1	3		1395.2	2	
1241.5	2		1327.5	2		1396.4	7	
1246.1	4		1329.3	1		1397.5	6	
1247.2	4		1331.3	6		1398.0	1	
1248.0	2		1333.9	8	double	1399.0	7	
1249.8	3		1335.3	2		1400.6	1	
1251.2	3		1336.1	8	double	1402.0	4	
1253.2	6		1337.6	6		1402.8	8	
1253.9	5		1338.7	7	double	1404.3	5	
1255.5	4		1340.9	1	double	1405.5	2	
1257.1	4		1342.4	8		1407.3	7	
1258.2	4		1343.6	1		1408.6	3	
1259.9	4		1345.4	8	double	1410.5	8	triple
1261.9	8		1347.2	9	double	1411.8	1	
1264.0	1		1349.1	2		1413.0	8	
1264.6	5		1350.2	3		1414.9	2	
1265.8	4		1350.8	3		1416.4	3	
1267.3	1		1352.5	8		1419.5	2	
1268.3	1		1353.6	8		1420.3	3	
1269.1	3		1355.5	7		1426.8	3	
1269.9	1		1357.3	6		1427.8	7	double
1270.7	4		1358.2	4		1429.0	3	
1271.5	4		1359.2	5		1430.1	7	
1272.0	1		1360.1	5		1431.1	3	
1273.3	3		1362.4	1		1433.0	8	double
1274.2	1		1363.4	8		1434.3	3	
1275.0	3		1364.3	3		1435.2	4	
1276.1	1		1365.8	5		1436.3	7	double
1277.1	6	double	1366.5	1		1438.0	4	
1279.0	1		1367.6	3	double	1439.1	1	
1279.8	5		1368.0	3		1441.0	8	
1281.2	4		1369.1	1	double	1442.8	1	
1282.6	1		1370.4	2		1443.6	7	
1283.4	6		1371.3	6		1445.2	4	
1284.5	5	double	1372.1	1		1446.2	6	
1286.9	5	double	1372.9	3		1447.4	2	?
1288.1	4		1374.0	1		1449.2	2	
1289.4	3		1374.5	2		1450.3	5	
1290.4	5		1375.5	1		1451.0	1	
1291.3	2		1376.1	1		1452.0	3	
1293.6	6	double	1377.2	6	double	1452.5	1	
1295.7	2	double	1378.0	1	double	1454.3	1	
1297.4	5		1380.2	[illegible]		1455.1	7	double
1299.5	1		1380.8	1		1456.3	4	
1300.0	3	double	1382.9	1		1457.4	6	
1302.5	2	double	1383.0	1		1458.4	6	
1307.5	2		1384.2	1		1460.1	5	double
1311.1	2		1385.6	2		1461.0	4	

SPECTRUM OF HYDROGEN MEASURED BY A DIFFRACTION GRATING—*Continued*

Wave-Length	Intensity	Character	Wave-Length	Intensity	Character	Wave-Length	Intensity	Character
1462.0	3		1535.0	6	double	1603.8	1	
1462.9	4		1536.7	1		1604.6	6	
1463.9	8		1537.5	7	double	1605.3	5	
1465.2	3		1539.2	5		1606.3	5	
1467.2	6	double	1539.9	2		1607.7	10	
1468.6	6		1540.6	2		1608.2	6	
1471.0	3		1541.6	7		1608.6	10	
1472.5	3		1543.9	2		1609.2	3	
1473.9	5		1544.7	8		1610.1	2	triple
1474.9	4		1545.5	2	double	1610.5	7	
1476.4	4		1546.4	6		1611.2	1	
1477.3	3		1547.4	7	double	1611.8	3	
1478.9	2		1548.3	1		1612.5	1	
1479.7	4		1549.9	7	double	1613.3	7	
1480.4	4		1550.6	7	double	1614.3	4	
1481.7	5		1551.5	2		1615.0	3	
1482.1	1		1553.3	10		1616.7	6	
1483.7	3		1554.9	3		1617.9	1	
1486.1	1		1555.6	1		1619.9	2	double
1486.9	9		1556.4	2		1621.1	7	double
1487.8	1		1557.4	1		1622.1	3	
1489.3	6		1558.7	1		1623.2	2	
1489.9	3		1560.0	1		1623.8	7	
1491.9	7		1561.1	2		1625.8	4	
1492.7	1		1562.2	4		1627.6	1	
1494.1	3		1563.0	1		1628.5	8	
1495.5	10	double	1564.0	1		1631.7	2	
1499.8	8		1565.1	3	double	1633.7	6	
1502.2	2		1567.1	5	double	1634.1	4	
1503.9	1		1569.2	6		1635.3	3	
1505.0	8		1569.7	1		1636.5	7	
1505.9	1		1571.3	1		1638.2	4	
1506.6	1		1571.7	7		1639.1	5	
1511.5	8		1574.3	5		1639.7	1	
1513.6	7		1577.2	8		1640.5	6	
1515.0	6		1579.2	4		1641.6	5	
1516.4	5		1581.0	7	double	1643.0	5	
1517.5	6	double	1584.1	7		1644.6	7	
1519.0	6		1585.7	7	double	1645.7	2	
1520.1	5		1587.6	3		1646.0	1	
1521.7	2		1589.0	8	triple	1647.8	1	
1522.5	2		1590.9	4		1651.8	1	
1523.4	8		1591.5	8		1654.2	2	
1525.4	5		1593.6	7		1662.9	1	
1526.6	2		1595.2	1		1667.4	2	
1527.5	4		1596.2	10		1670.2	1	
1529.7	3		1599.4	6		1671.6	2	
1530.9	6		1602.0	8		1672.4	2	
1532.1	6		1602.8	1		1674.6	1	
1533.2	6							

LINES OF UNCERTAIN ORIGIN PROBABLY DUE TO HYDROGEN

Wave-Length	Intensity	Character	Wave-Length	Intensity	Character	Wave-Length	Intensity	Character
1030.8	1		1148.8	2		1202.8	1	
1034.2	2		1151.2	2		1205.2	6	
1045.2	4		1160.9	10	double	1206.9	6	
1047.5	5		1164.0	6		1207.8	2	
1062.1	1		1166.5	6		1209.2	6	
1065.6	3		1169.2	1		1209.7	1	
1070.0	1		1172.6	1		1210.8	2	
1080.0	1		1174.9	1		1211.7	3	
1082.1	1		1176.2	5	double	1215.0	2	
1094.9	2		1178.5	3	double	1216.0	8	
1098.0	2		1180.8	7		1217.6	3	
1100.0	3		1182.7	4		1219.1	1	
1102.2	4		1185.0	2		1221.5	1	
1104.8	6		1189.0	7	double	1223.7	3	
1107.5	6		1198.6	2		1225.2	1	
1110.5	3		1200.2	2		1225.9	7	
1119.4	4		1201.8	3		1227.5	1	
1145.5	8	double						

THE RELATION BETWEEN THE SPECTRA OF SUN-SPOTS AND FOURTH-TYPE STARS

By WALTER M. MITCHELL

The recent investigations of Hale, Ellerman, and Parkhurst on the spectra of the stars of Secchi's fourth type have given a fresh impulse to the discussion of the question whether the peculiar spectrum of those stars is due to spots similar to those appearing on the Sun. A comparison is given[1] between the widened lines in the sun-spot spectrum and the lines in the spectra of fourth-type stars. The statistics of the widened lines are derived from the observations by Maunder during 1880, and those by Cortie during various periods prior to 1901. Their conclusion from the comparison is that the evidence favors strongly the view that spots like those on the Sun may form a characteristic feature of fourth-type stars.

Lockyer, by a somewhat similar comparison[2] between the spectra of third- and fourth-type stars and the widened lines observed in sun-spots at South Kensington, is led to the view that the fourth-type star is simply at a lower temperature, or at a more advanced stage of its life-history. The strong dark lines of its spectrum indicate stronger absorption, as in accordance with his theory of sun-spots the widened lines in their spectra are the results of absorption by cooler gas-masses.

On the other hand, Wilson supports the view that sun-spots are at a higher temperature than the surrounding photosphere, and, from the possible similarity of spot and fourth-type spectra, suggests that the fourth-type stars may be in reality hotter than those of preceding types.[3] The lack of brilliancy of the star is accounted for under the assumption that the temperature of the star is greater than that which permits the condensation of the vapors of certain elements to form a photosphere of the accepted type. It must be said, however, against this last statement that it is difficult to see how it would be possible for an intensely heated gas-mass to be exposed to the cold of space without suffering condensation somewhere in its outer layers.

[1] *Publications of the Yerkes Observatory*, **2**, 367.

[2] *Proc. R. S.*, **74**, 53, 1904. [3] *Monthly Notices*, **55**, 226, 1895.

The following table shows the results of a comparison of the sun-spot spectrum as observed at Princeton[1] with the lines in the spectrum of fourth-type stars recorded at the Yerkes Observatory,[2] and the lines in the spectrum of *a Orionis* observed by Keeler. The comparison is restricted to the region λλ 4861–6500.

EXPLANATION OF THE TABLE

The first column contains the wave-lengths of the lines in the sun-spot spectrum. Italics indicate that the line is of special importance, "R" that it has been seen reversed.

The second and third columns indicate respectively the probable origin of the lines as determined by Rowland, and the frequency of the line in the spot spectrum, estimated on a scale of ten.

The fourth column gives the conspicuousness of the line in the sun-spot spectrum, and indicates how greatly the line is affected. The scale ranges from 10 to −5; negative numbers indicate that the line is less conspicuous than in the photosphere. If discrepancies are noticed between the two latter columns and the corresponding columns in my table of spot lines, it is on account of subsequent observations which have been incorporated in this paper.

The fifth and sixth columns contain the wave-lengths and the intensities of the lines in the spectrum of fourth-type stars, as recorded by Hale, Ellerman, and Parkhurst.

The seventh and eighth columns give the same data for lines in the spectrum of *a Orionis*, intensity "E" indicating that the line is of equal strength with the corresponding line in the solar spectrum, "S" and "W" indicating that the line is respectively stronger or weaker than the corresponding solar line.

The ninth column is devoted to general remarks. A few bright lines in the red region of 152 *Schjellerup* are indicated by "(152)".

[1] *Astrophysical Journal*, **22**, 4, 1905.

[2] *Loc. cit.*

Affected in Sun-Spots				Fourth-Type Stars		Third-Type Stars		Remarks
Wave-Length	Origin	Frequency	Intens.	Wave-Length	Intens.	Wave-Length	Intens.	
F**4861.53	*H*	3	..	4861.3	10	4861.5	E	
4864.92	*V*	9	9	4865.1	2	4864.4	S	
4871.51	*Fe*	4	4	4871.5	2–3	4871.8	E	
4872.33	*Fe*	4	4					
4875.67	*V*	9	10	4875.5	2	4875.6	S	
4881.74	*V*	7	7	4881.6	3–4	4882.0	S	
4882.34	*Fe*	2	3					
4885.26	*Ti*	7	7					Given by Hale as due to *Fe, V*.
4885.96	*Cr*	4	4	4886.0	4			
4886.13	*Cr*	2	5					
4890.95	*Fe*	5	7	4890.3	1–2			Given by Hale as due to *V*.
4891.68	*Fe*	5	7					
4900.09	*Ti, La*	7	5	4900.1	2	4900.3	S	Given by Hale as due to *Ti, V*.
**4919.17	*Fe*	2	3			4919.2	E	
4920.68	*Fe*	2	4					
4921.15	*La*	2	2	4920.9	2–3	4920.7	E	
4921.96	*La, Ti*	6	7					
4925.75	*Ni*	2	−1	4925.2	1			Given by Hale as due to *Fe*.
4937.90	*Ti*	5	5			4937.5	S	
4957.48	*Fe*	3	4			4957.6	E	
4957.79	*Fe*	3	4	4958.4	2			
4958.43	*Ti*	2	5					
4981.91	*Ti*	3	4	4981.8	w			
4982.99		2	8					
5188.86	*Ti*	1	2	5189.2	1–2			
5191.63	*Fe*	2	3			5191.6	E	Reversed? in spot once.
*5195.11	*Fe*	1	4			5195		
*5202.52	*Fe*	4	5	5202.4	1			
*5204.77	*Fe–Cr*	5	5			5204.8	S	
*5205.90	*Y*	1	−4	5205.8 to 5210.1	10			
*5206.22	*Cr–Ti*	5	5			5206.2	S	
*5208.60	*Cr*	4	5			5208.6	S	
*5210.56	*Ti*	2	5			5210.6	S	
5219.88	*Ti*	8	9			5219.6		Third-type line not in Sun?
**5226.71	*Ti*	2	..	5226.5	7			Weakened three times, reversed once in spot.
*5227.04	*Fe–Cr*	6	..					
*5233.12	*Fe*	3	5	5234.0	3			Given by Hale as due to *V*.
**5234.79		2	−3					
5238.74	*Ti*	9	8	5239.8	2			
5239.14	*Cr*	9	7					
5247.23 R	*Fe*	4	5	5247.4	3–4	5247.7	S	Reversed three times in spot.
*5247.74 R	*Cr*	7	5					Reversed five times in spot.
5250.39 R	*Fe*	10	9	5251.5	3–4	5250.6	S	Reversed seven times in spot.
5252.28	*Ti*	7	6			5252.3	S	

Affected in Sun-Spots				Fourth-Type Stars		Third-Type Stars		Remarks
Wave-Length	Origin	Fre-quency	Intens.	Wave-Length	Intens.	Wave-Length	Intens.	
5255.30 R	*Cr*	3	4	5255.6	1–2	5255.1	S	Given by Hale as due to *Fe, Cr.*
5255.49	*Mn*	5	6					
5265.32	*Cr*	2	4	5265.9	1			
5266.14	*Ti*	6	5					
E**5269.72	*Fe*	3	5	5270.4	4–5	5269.7 5270.4	S S	
5296.87	*Cr*	6	6			5297.0	S	
5297.41	*Cr–Ti*	7	6					
5298.19	*Cr*	3	3	5298.2	3–4	5298.0	E	
5298.45	*Cr*	3	–2					
5298.67	*Ti*	3	–2					
5302.48	*Fe*	1	4	5302.5	1–2			
5307.54	*Fe*	1	3	5307.5	1			
5321.29	*Fe*	3	4	5320.8	2–3			
*5328.24	*Fe*	4	5	5329.0				
*5329.33	*Cr*	3	5		3–4			
5340.12	*Fe*	1	–2	5341.5		5341.2	S	
5341.34	*Fe, Mn*	2	–2		3			
*5345.99	*Cr*	3	–1			5346.0	S	
5348.51	*Cr*	4	–2			5348.5	S	
5349.65	*Ca*	4	2	5350.0	3			
5349.93	*Fe*	1	–2					
5366.83		4	5	5366.6	2			
5369.78	*Co–Ti*	5	5			5370	E	
**5371.70	*Fe–Cr?*	3	5	5371.7	7–8	5371.6	S	
5383.57	*Fe*	3	4	5384.7	1			
5396.78	*Ni*	4	6	5397.3	4			Given by Hale as due to *Fe, Ti.*
*5397.34	*Fe*	4	5					
5404.36	*Fe*	2	4			5404	W	
*5405.99	*Fe*	3	7	5406.4	1	5406	S	
5407.69	*Mn*	5	7	5408.3	2–3			
5409.02		4	8					
*5410.00	*Cr*	4	5	5410.4	2–3	5410.0	S	
5413.89	*Mn*	3	5	5414.2	1–2			
5420.55	*Mn*	7	6	5420.2	3			
5424.29	*Fe*	2	4			5424.2	E	
5426.47 R		10	10			5426.5		Reversed once in spot.
5429.35	*Ti?*	5	3	5430.2	3	5429.9	S	
**5429.91	*Fe*	3	4					
**5432.75 R	*Mn*	9	10			5433.0	S	Reversed three times in spot.
*5434.74	*Fe*	4	4	5434.3	1–2	5434.7	S	Given by Hale as due to *Fe, V.*
**5447.13	*Fe*	2	4	5447.8	7	5447.0	S	
5460.72		9	10	5460.9	1–2	5461.0		
5461.76 R		7	7					
5462.71 R	*Ni*	9	9			5463.0	W	Reversed six times in spot.
5466.61	*Fe*	4	5	5467.3	1–2			
5467.20	*Fe*	3	2					

Affected in Sun-Spots				Fourth-Type Stars		Third-Type Stars		Remarks
Wave-Length	Origin	Frequency	Intens.	Wave-Length	Intens.	Wave-Length	Intens.	
5474.44	*Ti*	6	7	5474.5	1–2			Given by Hale as due to *Fe*.
5477.90	*Ti*	7	7	5478.0	1–2	5477	E	
5483.31 R	*Fe*	3	4	5483.0	1–2			Reversed twice in spot.
5483.57	*Co*	6	5					
*5497.74	*Fe*	7	5	5498.0	4	5497.6	S	
*5501.68	*Fe*	4	6	5501.8	2	5501.6	S	
5506.09 R	*Mn*	6	8	5507.1	1	5507.0	S	
*5507.00	*Fe*	1	4					
5512.74	*Ti*	4	6	5512.4	2–3			
5513.20	*Ca*	3	5					
5525.77	*Fe*	2	5	5525.4	1–2			
5538.74 R	*Fe*	8	10	5539.5	7			Reversed seven times in spot.
5546.73 R	*Fe*	5	4	5546.6	1–2			
5547.22	*Fe—V*	6	5	5548.3	2			
5556.0		1	6	5556.4	1–2	Region here same as in Sun		Line not in photospheric spectrum.
5573.33		1	3	5573.7	1			
5583.1		1	4	5583.9	8			Line not in photospheric spectrum.
5584.53 R	*V*	6	4					
*5588.99	*Ca*	4	4	5589.2	1			
5594.69	*Ca*	3	4	5594.7	1–2			
5598.71	*Ca*	2	3			5598.5	S	
5619.82 R		5	5	5620.3	2–3			Reversed in spot twice.
5620.72 R	*Fe*	4	–3					Obliterated once, reversed twice.
5625.09		7	6	5625.1	4			Given by Hale as due to *Fe*, *V*.
5644.37	*Ti*	7	6	5644.2	1–2			
5657.66 R	*V?*	9	6	5658.2	1–2	5658.5	S	Reversed four times in spot.
**5658.10 R	*Y*	4	5					
5658.88	*Cr*	1	3					
5663.16	*Ti-Fe-Y*	5	4			5663.0	S	
5671.07	*V*	9	9	5671.3	1–2			
5672.05	*Sc*	9	8					
5708.32	*Fe*	5	3	5708.3	2–3			
5712.10	*Fe*	7	4	5712.8	1–2	5712	S	Always reversed in spot.
5712.36 R	*Fe*	8	5					
5712.99	*Cr*	3	3					
5727.27	*Ti–V*	7	8					
5727.87 R	*Cr?–V?*	10	10			5727.2	S	
5731.44 R	*V*	10	10	5731.6	3–4	5732.0	S	
5731.98	*Fe*	1	–2					
5743.18		2	5	5743.7	2			
5743.65	*V*	7	7					
5748.17 R	*Fe*	5	5	5749.4	2			Reversed five times in spot.
5748.57 R	*Ni*	8	9					

Affected in Sun-Spots				Fourth-Type Stars		Third-Type Stars		Remarks
Wave-Length	Origin	Frequency	Intens.	Wave-Length	Intens.	Wave-Length	Intens.	
5762.49	*Ti*	9	5	5762.5	2			
5778.68	*Fe*	2	3	5778.0	1			
5784.88 R	*Fe*	6	4	5784.8	3			Always reversed in spot.
5798.08		7	−2	5798.1	1			
5798.40	*Fe*	1	2					
5823.91		3	4	5822.9	2			
5848.34	*Fe*	4	3	5848.5	1			
5856.31	*Fe*	2	3			5856		
D_3**5875.98	*He*	3	3			5875		
D **5894.2	*Na*	5	5	5894.3	10	(??)		
5922.33	*Ti*	8	6	5921.9	1			
5944.95	*A(wv)*	3	5	5945.9	1			
6058.38		6	5	6059.1				
6085.47 R		8	7	6086.1				(152)
6098.46 R		3	3	6098.5	3			
6098.87	*Ti*	10	3					
6119.74	*V*	9	8	6119.0	2			
6129.19 R	*Ni*	10	4	6130.5	B 8			Reversed five times in spot.
6131.79 R		1	4					(152)
*6154.44 R	*Na*	10	8	6154.9	B 2			Reversed six times in spot. (152) (152)
6200.53 R	*Fe*	5	4	6200.9	B10			Given by Hale as due to *Ca*, *O*.
6269.08 R	*V*	10	8	6269.6	10			Reversed in spot seven times.
6271.48	*Fe*	3	3					
6330.31 R	*Cr*	9	9	6330.2	B 1			(152)
6355.25	*Fe*	3	5	6357.6	3			
6358.90 R	*Fe*	5	5					

A comparison of this kind is made with great difficulty on account of the very great difference in the dispersive powers employed in the two kinds of spectra. The spectra of the fourth-type stars were obtained in most instances with the three-prism spectrograph of the Yerkes Observatory, while for the sun-spot spectrum I have used the third order of a large Rowland grating, the ratio of the two resolving powers being about 1:14. To avoid this difficulty, if possible, the attempt was made to secure for the comparison the low dispersion spectrum of the umbra of a large sun-spot. This was done by substituting a single reflecting prism for the grating previously used, while the light from the spot umbra only was allowed to fall on the slit, the

remainder of the Sun's surface being properly screened off. The results were entirely negative: the brightness of the sky spectrum completely overpowered that from the spot, so that it was questionable, at first glance, whether the spot or a portion of the photosphere was on the slit. The appearance was simply that of the normal solar spectrum, with the exception that the Fraunhofer lines were of slightly greater intensity than usual. There was no indication whatever of bands or of bright regions.

The wave-lengths of the lines in the spectrum of *α Orionis* agree remarkably with those of the corresponding spot lines, but this is as would be expected owing to the greater brilliancy of this star, allowing greater dispersion and more accurate determination of wave-length.

There are many instances where several sun-spot lines have approximately the wave-lengths of the fourth-type lines, and in these cases it was found necessary to group the spot lines together, forming, as it were, one line. A number of fourth-type star lines agree closely in wave-length with strong Fraunhofer lines in the solar spectrum, while near the Fraunhofer lines are frequently faint lines which become very prominent in the spot spectrum, while the Fraunhofer lines are not affected, as instanced by the star line λ 5255.6, whose origin, as given by Hale, is *Cr, Fe.* The corresponding solar line is probably λ 5255.12, which is not affected in sun-spots, while the neighboring faint *Mn* line at λ 5255.49 is usually considerably widened. The star line at λ 5625.1 due to *Fe, V* has probably its counterpart in the solar line at λ 5624.77—*Fe, V.* This line I have never seen affected in the spot spectrum, but the near-by faint line at λ 5625.09 has been frequently widened and intensified. Still another instance is the star line λ 5731.6—*Fe, V*, the solar counterpart of which is probably the line λ 5731.98—*Fe.* This line has only once been observed in the spot spectrum, and then as "thinned," while near it the line at λ 5731.44 is one of the strongest spot lines. While it is to be noted that in most cases the wave-length of the star line agrees more closely with that of the spot line than with the wave-length of the stronger Fraunhofer line, it is to be remembered that the difference in wave-length in any case is considerably less than the limit of the resolving power of the Yerkes spectrograph in the given region, hence making it very uncertain whether the star line corresponds to the spot line or to the unaf-

fected Fraunhofer line. That the latter is the case seems to be borne out by the fact that there are many instances of agreement between strong Fraunhofer lines and star lines, while there are very few instances where faint lines in the solar spectrum which are much affected in the spot, have strong counterparts in the spectra of the fourth-type stars.

Again the star line may have for its counterpart a group of fine lines, only a few of which are affected in the spot; an instance is the star line λ 5298.2: in the solar spectrum there is a group of seven rather faint lines near this wave-length, only two of them being much affected in the spot spectrum. Another instance is the star line λ 5658.2, due to *V*, which falls in a group of six solar lines of varying intensities, only two of which are much affected in the spot spectrum.

Hence it will be seen that under the circumstances it is almost impossible to make a satisfactory comparison of the two spectra, and it tends to show that it is questionable whether we have any grounds for their supposed similarity. As it is impossible to tell from the wave-lengths of many of the star lines which is the corresponding solar line, the conclusions of other observers appear to have been based merely upon the apparent similarity of wave-lengths.

Now as to the intensities of the corresponding lines. It will be noted, on consulting the table, that even by giving the star lines the "benefit of the doubt" the agreement with the sun-spot spectrum is slight. The total number of star lines in the region $\lambda\lambda$ 4861–6500 is 143; in the table are given 90 which have approximately the same wave-lengths as lines in the spot spectrum, while 75 of these have their wave-lengths in fairly close agreement. But of the 75 there are only 14 lines (10 per cent. of the whole) which are prominent in both stellar and spot spectra. There are 16 lines which are prominent in the spot, while either faint or absent entirely from the star spectrum, and there are 5 which are the other way.

According to Hale,[1] the titanium lines show great similarity in the two spectra. He states: "No line which is missing in the star has an intensity greater than 1 in the arc, or a widening greater than 4 in sun-spots." With this I cannot agree, for the following lines are absent from the star, are strong in sun-spots, and have arc intensities

[1] *Loc. cit.*, 373.

indicated: λ 4913.8 (3), λ 5219.8 (2), λ 5471.4 (2) λ 5899.5 (3).[1] It may also be noted that the titanium lines λ 5336.97 and λ 5675.65 each have intensity 2 in the star and have. not been observed in the spot spectrum at Princeton.

The magnesium lines, according to Hale, play a significant part in the fourth-type spectrum, the *b* group are a prominent feature, and other lines are present. It is to be noted that they are of small importance in the spot spectrum, no observations of magnesium lines being recorded at Princeton.

In contrast to this is the behavior of the manganese lines, which are of relatively great importance in the spot spectrum, and are apparently of minor consequence in the spectra of fourth-type stars.

Carbon, whose presence in the fourth-type stars is so strongly indicated by the absorption bands in their spectrum, is apparently absent from sun-spots.[2]

Hence, summing up the evidence, it is seen that of 90 possible coincident lines in the two spectra, only 14 are sufficiently intense in both spectra to warrant any conclusions as to the similarity of the sources of light. Likewise the non-agreement between the lines of magnesium, manganese, and carbon, with the irregularities in the behavior of the titanium lines, are facts against the similarity of the two spectra. Therefore from the Princeton sun-spot observations it seems improbable that spots such as exist on the Sun constitute a characteristic feature of the fourth-type stars.

PRINCETON, N. J.,
January 24, 1906.

[1] Hasselberg, *Astrophysical Journal*, **4**, 212, 1896.

[2] *Ibid.*, **22**, 6, 1905.

LINE STRUCTURE. II. THEORY OF BROADENING, DOUBLING, AND REVERSAL

By P. G. NUTTING

Considerable data relating to the structure and behavior of spectrum lines has accumulated during the last few years. Michelson and Fabry and Perot made investigations with the interferometers bearing their names. Recently James Barnes,[1] with a Fabry-Perot interferometer, has investigated the prominent lines of mercury, cadmium, thallium, zinc, and hydrogen. R. A. Houstoun[2] and Ludwig Janichi[3] have examined the same lines with echelon spectroscopes. The writer, also using an echelon, has recently investigated a great many of the visible lines of many of the elements, chiefly with a view to establishing types of variability in line structure. The present paper is a discussion of the results described in a previous paper.[4]

It was found that five types of behavior covered the observations, and that fully 95 per cent. of all lines observed were included in two classes, (2) and (3), being about equally divided between them. These five types are as follows: (1) lines like the chief mercury and helium lines, having components of the nature of distinct spectrum lines; (2) lines that simply broaden indefinitely as their intensity is increased, about half of which show superposed structure just before reversal; (3) lines that twin at an early stage with sharp, widely separated components; (4) lines that triple in the intermediate stage between single narrowness and reversal; (5) lines, few in number, that are unsymmetrical and vary irregularly. Attention is here chiefly directed toward the numerous lines of the second and third types. Lines of the first type are to be treated as miniature spectra. Regular tripling, type (4), appears to be a special case of twinning in which the central

[1] *Astrophysical Journal*, **19**, 190–212, April 1904.

[2] *Phil. Mag.*, (6) 7, 456–467, May 1904.

[3] Inaug. Diss., Halle, 1905.

[4] "Line Structure, I," *Astrophysical Journal*, **23**, 64–79, January 1906.

component remains, while lines of the last type require only some simple special assumption as to structure for explanation.

The commonest types of line growth are shown in the accompanying figures. Lines of type (2), remaining single until they reverse, possess a luminosity curve either like an inverted Λ (Fig. 1), or like an inverted ∩ (Fig. 2). The former has diffuse wings, a bright center, and disappears as a very narrow *line*. The latter is broad

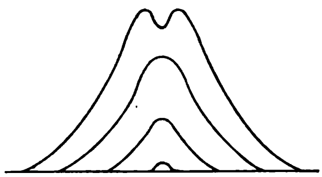


FIG. 1

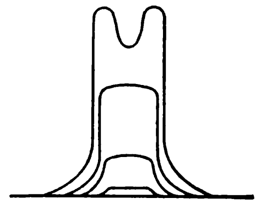


FIG. 2

and uniform in brightness, has barely perceptible wings, and disappears as a *ribbon* of light. *Cu* λ 5218 is characteristic of the former, *Cu* λ 5104 of the latter type. The iron lines reverse somewhat as shown in Fig. 3. They twin at an early stage, appearing exactly like a pair of adjacent lines with very sharp edges. As the intensity is increased, the components retreat from each other, broaden, and finally show reversal proper. The figures exaggerate the actual effects and ignore second-order phenomena like superposed structures; but only the effects shown are to be discussed in this paper.

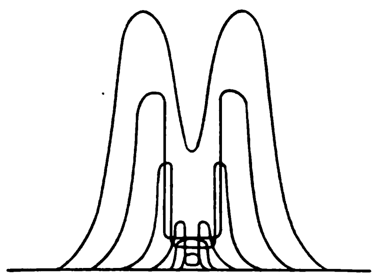


FIG. 3

The resolving power of an echelon grating is sufficient to justify considerable detail in the description of the structure of a line 0.2 t.-m. broad. An echelon of thirty plates, each 10 mm thick and differing in width by ½ mm from its neighbors, has a dispersion approximately the same as that of a 21-foot grating in the second order. Its resolving power is about ten times as great as that of such a grating, being equal to the distance between adjacent orders divided by the number of plates. Calculation indicates that the narrowest lines would appear 0.010 t.-m. broad, but one of the satellites of

the green mercury line appears considerably narrower than this limit.

As to its truthfulness, the echelon appears to be comparable with the prism and far superior to an ordinary reflection grating, giving always a normal spectrum free from false lines. Independent observers using instruments from different makers obtain results in the highest possible agreement.

LIMITING CASES OF REVERSAL

Before discussing line structure as dependent upon the individual sources, let us examine carefully the effects that might be produced by lack of homogeneity in the radiating body of gas. Might not such doubling as is shown in Fig. 3 be merely an extreme case of reversal by absorption, not involving twin modes of vibration in each source nor the existence of two different classes of radiators? Assuming Kirchhoff's law

$$E=AJ\,,$$

and the law of non-homogeneity

$$E_{12}=E_1+E_2-A_1E_2\,, \tag{1}$$

and extreme cases of radiation (E) and absorption (A) from the layers of gas 1 and 2, what would be the extreme types of line structure possible?

The condition for reversal usually given[1] is that the emission E_{12} from two layers of gas shall be less than the emission E_2 from the rear layer alone. This condition gives

$$E_1<A_1E_2 \text{ or } E_2>J_1\,; \tag{2}$$

hence for reversal the emission of the rear layer must be greater than the front layer could emit if it were infinitely thick, or greater than a perfect radiator or black body could emit if in thermal equilibrium with it.

But this condition, while necessary, is by no means sufficient; with this condition holding, the effect of the absorbing front layer might be merely to pare off the tip of the emission curve E_2 without any reversal at all. To be sufficient a more general condition must be imposed.

[1] See Kayser, *Handbuch der Spectroscopie*, 2, p. 53.

Reversal may be observed when there is a minimum between two maxima in the emission wave-length curve. Hence the necessary and sufficient condition for reversal is that the wave-length derivative of equation (1) shall change sign more than once, that is, shall have not one but three real roots in the neighborhood of the maximum. The derivative of (1) is

$$\frac{dE_{12}}{d\lambda}=\frac{dE_1}{d\lambda}\left(1-\frac{E_2}{J_1}\right)+\frac{dE_2}{d\lambda}\left(1-\frac{E_1}{J_1}\right)+\frac{dJ_1}{d\lambda}\frac{E_1E_2}{J_1}\,, \tag{3}$$

which for convenience in discussion may be written

$$E^1_{12}=E^1_1L+E^1_2M+J^1_1N\,. \tag{4}$$

The roots of the right-hand member of (3) give the necessary and sufficient conditions for all kinds of reversal from a heterogeneous radiator of two layers. Complete reversal, auto-reversal, reversal due to Doppler shift, and many other kinds are special cases dependent upon various differences in nature, state, and thickness of the two layers.

Now the derivatives E^1_1, E^1_2, and J^1_1, may be either positive, negative, or zero, and that, except in special cases, independently of one another. By the necessary condition (2), E_2 must be greater than J_1, hence L is always negative. M is always positive, since E_1 can never be greater than J_1. N is essentially positive.

When the rear layer is an incandescent solid, conditions give $E_2=J_2>J_1$ at or near maxima of E_1; hence E^1_{12} is opposite in sign from E^1_1 for all wave-lengths near maxima. Reversal is most pronounced when E_1 approaches J_1 in value, since this condition—absorbing layer thick—makes E^1_{12} a maximum. This is the case of complete reversal. Auto-reversal occurs when both layers are of the same kind of gas, and hence E_1 and E_2 have identical roots. In this case reversal occurs at or near (depending upon the magnitude of the final term) these roots when $E_2>J_1$, whether E_1 be small in comparison with J_1 or nearly equal to it. Reversal will be symmetrical only when the greatest positive and negative values of E^1_{12} are equal in magnitude, and this is a very special case. Equation (4) shows that dissymmetry may be caused by differences in thickness or of state of the emitting layers, or even by the mere position of the maxima relative to the maximum of the correspond-

ing black-body curve J_1. If the two layers are identical in all respects, E_{12} can have no maximum or minimum other than those of E_1 and E_2; hence lines from a homogeneous source cannot be reversed. In the capillary of a Plücker tube, viewed from the side, conditions are such that E_1 and E_2 have the same roots, but E_1 is vanishingly small. Hence by (4) reversal requires that not only must E_2 exceed J_1 but $E_1'' L$ must exceed E_2''. That is, the curvature of the emission curve E_2 must be less than L times the curvature of E_1. Since, under the conditions assumed, E_2 can be little if any greater than J_1, L is small, and reversal cannot be deep and can occur only under extreme conditions.

Consider the conditions necessary for the deep, sharp reversal illustrated in Fig. 3. The sharp definition of the components requires large values—approaching infinity—of the derivative E_{12}^{1}, while depth of reversal requires that E_{12} have very small values—approaching zero—at the minimum. But by (4) E_{12}^{1} cannot be greater in absolute value than either E_1^{1} or E_2^{1} alone, since L and M are of opposite sign and J_1^{1} is small. Hence a reversal cannot be more sharply defined than an unreversed line of equal intensity. Further, by equation (1), E_{12} cannot be less than E_1 at any wave-length, but deep reversal requires that E_1 be large. Both this and the preceding condition are of doubtful existence so far as observations go, so that the evidence is all in favor of the early doubling of the iron lines being due to causes other than absorption.

A complete discussion of reversal will be possible only after the function E has been constructed. The emission E is a function of four classes of arguments: (1) arguments specifying the nature of the radiating body; (2) arguments like temperature, pressure, internal energy, etc., specifying its condition; (3) mechanical arguments like thickness, specifying form and dimensions; and lastly, (4) wave-length or frequency of the emitted radiation. Kirchhoff's law and the law of heterogeneity (1) hold of course whatever the forms of the general function E. While we have not sufficient data at present to construct the complete emission function of any of these arguments, it will be useful here to set up a thickness function with the understanding that it is but tentative until more exact data shall substantiate it or cause its rejection.

The partial derivative of the complete emission function must have a single real root at infinity, since it is asymptotic to $J(\lambda)=$ constant. Hence write

$$dE=(E_\infty - E)\,\phi\,d\,\theta\,,$$

where θ is the thickness of the radiating layer, and ϕ is a function of wave-length, nature of the radiator, condition of the radiator, or anything else except thickness. Integrating,

$$E=J\,(1-e^{-\phi\theta})\,, \tag{5}$$

provided the emission E_∞ of an infinitely thick layer is identical with the emission J of a perfect radiator or black body in thermal equilibrium with it.

As a severe test of this thickness function (5), substitute in equation (1) for two layers of thickness θ_1 and θ_2 of the same nature and in the same condition; hence $\phi_1=\phi_2$ and $J_1=J_2$. This substitution gives on reduction and collection,

$$E_{12}=J\,(1-e^{-\phi\,(\theta_1+\theta_2)})$$

as required.

In applying the thickness function (5) to the conditions for reversal expressed in (4), note that

$$\frac{dE}{d\lambda}=\frac{dE}{d\phi}\,\frac{d\phi}{d\lambda}=\theta\,J\,e^{-\phi\theta}\,\frac{d\phi}{d\lambda}\equiv\theta\,J\,\Theta\,\phi^{1}\,.$$

Hence the condition for reversal (4), expressed in terms of thickness, may be written

$$E_{12}=\theta_1\,\Theta_1\,\phi_1^1\,(J_1-E_2)+\theta_2\,\Theta_2\,\phi_2^1\,J_2\,\theta_1+J_1\,J_2\,(1-\Theta_1)\,(1-\Theta_2)\;. \tag{6}$$

As before, $E_2>J_1$ is a necessary condition for reversal, hence J_1-E_2 is always negative. Only the derivatives ever change sign. All other quantities are essentially positive.

Equation (6) shows the effect of the thickness of the emitting layers on the position of the reversal, its symmetry, sharpness, and depth. We may note here that increasing the thickness θ_1 of the reversing layer (a) displaces the reversal away from the corresponding black body maximum; (*b*) sharpens the reversal on the side toward the larger waves, producing the opposite effect on the other side, and hence, (*c*) producing greater dissymmetry, while (1) and (5) show (*d*) that the depth of reversal is thereby increased. The thicker both layers, the greater the values that E_{12}^1 may have

and the less the value of E_{12} at the minimum; hence the deeper and sharper the reversal.

In the capillary of a Plücker tube viewed laterally, any reversing layer must be extremely thin, if existent; hence reversal could hardly amount to more than a mere dimple in the emission maximum. Such doubling as is depicted in Fig. 3 would require a thick reversing layer to produce such depth of reversal. But a thick reversing layer would produce diffuse boundaries to the reversal, while, as a matter of fact, the edges are extremely sharp, so that here again the doubling can hardly be regarded as a reversal. If then mere heterogeneity of condition is insufficient to produce the effects observed, we must turn to the radiators themselves for an explanation.

THE EMISSION OF BROAD, DOUBLE AND MULTIPLE LINES

Our problem then is to relate not only the amount but the quality of the emission from a body to the internal energy and nature of the body. Since the line structure varies directly with the energy of the source, the radiator itself must be modified by the energy which it transforms. The broadening to be accounted for is of the order of 10^{-4} to 10^{-6}; hence is to be treated as a second-order effect.

Broadening may be due to: (1) the effect of damping by radiation on the period of the radiator; (2) disturbances caused by impact; (3) an aggregate effect of Doppler shifts due to motion of the radiator along the radius of vision; (4) Doppler effects due to rotation of the radiator; and lastly, (5) and (6), the effect of motions of translation and rotation on the elasticity of the radiator, if this is electromagnetic in its nature.

Before discussing these effects, let us consider briefly the general relations existing between frequency (p) and the inertia (m), viscosity (s), and rigidity (r) of any body subject to elastic and dissipative forces. If x, $\dot{x}$, and $\ddot{x}$ represent respectively the displacement, velocity, and acceleration of any part, then its motion will be governed by the function,

$$m\ddot{x}+s\dot{x}+rx\,,$$

and its frequency will be given by the roots of the equation,

$$-mp^2+isp+r=0. \tag{7}$$

1. Broadening by damping. In the equation just written the damping factor is $s/2m$, while damping affects the period by an amount $s^2/4m$. For a green line $p=7\times 10^{15}$, and if but 0.005 t.-m. broad—an extremely narrow line—$d\lambda:\lambda=10^{-5}$. Hence we have

$$\frac{dp}{p}=\frac{1}{p}\cdot\frac{s^2}{4m}=\frac{d\lambda}{\lambda}=10^{-5},$$

so that the damping $s/2m>1.4\times 10^{11}$—a value at least a million times greater than the greatest which would permit of periodic motion, while interference experiments lead us to infer a damping so slight that at least 10^5 effective oscillations are executed after each excitation.

2. Broadening by disturbances caused by impact would be of the nature of faint, diffuse wings to relatively sharp and narrow lines, since all kinetic theory and spectroscopic evidence indicate that the time occupied by impact is very much less than the time elapsing between impacts, or even the time occupied in radiating except at pressures of many atmospheres. There is little, if any, evidence for broadening of this nature at atmospheric pressure or less.

3. Broadening by the Doppler effect has received considerable attention by F. Lippich[1], Rayleigh[2], A. A. Michelson[3], and others. If V is the velocity of light and u is the component of the velocity of the radiation along the visual radius, then by Doppler's principle

$$\frac{d\lambda}{\lambda}=\frac{u}{V}=10^{-5}$$

for a green line 0.05 t.-m. broad. This gives $u=10^5$ cm/sec, a velocity which kinetic theory assigns to the molecules of gases at ordinary temperatures and pressures. The aggregate of such effects would be an emission curve E resembling the probability curve in form, and having a mean width varying roughly as the square root of the internal energy and inversely as the square root of the density. The molecular Doppler effect then appears sufficient to account for simple broadening, but could not cause twinning or any structure other than that of the simple probability-curve type.

[1] *Pogg. Ann.*, **139**, 465–479, 1870. [2] *Phil. Mag.*, (5) **37**, 296–304, 1889.
[3] *Astrophysical Journal*, **2**, 251–263, 1895.

4. Rotatory motions of the radiator might give a Doppler effect similar to the effect of translation, but only a tenth to a hundredth as great, hence would be masked by the latter and need not be considered here.

5. If the generator of radiation is a distorted aggregate of electrical charges or charged particles, we may calculate the order of the effect of their motion of translation on their rigidity and hence on their frequency. Electromagnetic theory shows that the electromagnetic forces tending to preserve the configuration of such an aggregate always contain a factor varying from

$$1-\frac{u^2}{V^2} \text{ to } \left(1-\frac{u^2}{V^2}\right)^{\frac{1}{2}},$$

according as the force is acting in a line parallel or transverse to the line of motion of the aggregate as a whole. This factor would affect the frequency by an increment varying from a half to a fourth of u^2/V^2, since the frequency varies as the square root of the rigidity r and u^2/V^2 is small compared with unity. Hence for a moderate broadening, $d\lambda:\lambda=10^5$, we have

$$\frac{dp}{p}=\frac{u^2}{V^2}=\frac{d\lambda}{\lambda}=10^{-5}$$

and hence for

$$V=3\times 10^{10},\ u=10^8 \text{ cm/sec}.$$

Since an equal broadening by the Doppler effect would require a mean velocity of but 10^5 cm/sec., it appears that the electromagnetic effect would be completely masked by the Doppler effect.

6. The effect of rotation on the elasticity of a radiator cannot be determined by purely mathematical means without assuming some form of structure of the radiating aggregate. This has been accomplished by J. J. Thomson[1] for the special case of a limited number of charged particles arranged in a ring and rotating about its axis. Rayleigh[2] has considered the case of an atom containing a very large number of negatively charged particles. Both writers have developed frequency formulas depicting spectral series, but without considering second-order effects involving the width of lines.

[1] "The Structure of an Atom," *Phil. Mag.*, (6) 7, 237–266, March 1904.

[2] *Phil. Mag.*, (6) 11, 117–123, January 1906.

Without assuming any particular structure, consider the effects that rotation may have on the frequency of a radiator. A neutral aggregate cannot radiate, whatever its motion, unless it possess a finite external field. It appears to be both necessary and sufficient that gases at ordinary temperatures and pressures be constituted of such neutral aggregates. A gas composed of aggregates possessing a finite external field on account of either structure or lack of neutrality, could possess permanent thermal equilibrium only when subject to very moderate acceleration. Neutral aggregates may acquire a temporary external field by distortion or a quasi-permanent field by the addition or removal of a charge or charged particle, quasi-permanent referring to a time long in comparison to the time required for recovering from distortion.

Once possessing an external field, an aggregate may in general give rise to three different types of radiation corresponding to the three possible types of acceleration. (1) Oscillations of configuration about a mean configuration, corresponding to the different modes of vibration of the aggregate. Relations between frequencies would depend entirely upon the structure of the aggregate. Radial and tangential distortion would, in general, give rise to two distinct classes of related frequencies. (2) Rotation of an aggregate about any axis would give rise to radiation having a frequency equal to the (temporary) angular velocity of the radiator. If this angular velocity varies from time to time, or if neighboring aggregates differ in angular velocity, then a mass of aggregates will give a radiation frequency curve resembling the probability curve, having corresponding parameters. (3) Rectilinear acceleration, if sufficiently great, would give rise to aperiodic radiation. The radiation of this type from a mass of aggregates would be distributed about a maximum according to the probability law.

In any case the acceleration—central or linear—must be of the order of 10^{20} cm/sec.^{2} or more before the amount of the radiation becomes an effect of the first order. The intensity of the radiation from each generator is roughly proportional to both velocity and acceleration.

Consider now the effect of rotation on the frequencies of the radiation due to distortion. Neglecting effects of lower order, a

slight increase or decrease δr in the rigidity r of an aggregate will in general cause a slight increment or decrement δp to the frequency of each mode. Hence if p_0 be a frequency when stationary, the frequency when in rotation will be p_0 plus or minus an increment $\omega = \delta p/2$, or

$$p = p_0 \pm \omega. \tag{8}$$

For a pure oscillation of configuration without rotation $p = p_0$, since in this case the rotation, and hence the effect of rotation, is null. On the other hand, for a pure rotation without distortion, p_0 disappears and $p = \omega$; hence ω is to be identified with the angular velocity-frequency of the radiating aggregate. The identity of ω is to be regarded as mathmetically only tentatively established, but physically it appears to be both necessary and sufficient.

For a line half a tenth-meter wide in the green $d\lambda.\lambda = 10^{-4}$; hence for ω we have

$$\frac{dp}{p} = \frac{\omega}{p} = \frac{d\lambda}{\lambda} = 10^{-4},$$

from which $\omega = 3 \times 10^{11}$. For an aggregate of 10^{-8} cm radius this angular velocity corresponds to a rim speed of 3×10^3 cm/sec.—of just the order to be expected in a gas in which the mean relative velocity is 10^5 cm/sec. and rotation is caused by grazing impact. Thus the observed broadening is not greater, is in fact somewhat less, than is to be expected from equation (8) with ω identified as the angular velocity of the atom.

A frequency $\omega = 3 \times 10^{11}$ corresponds to a wave-length $\lambda = 0.6$ mm $= 600\mu$. But the broadening of a spectrum line by (8) does not necessarily imply a coexistent emission band far in the infra-red, for a frequency of 3×10^{11} is too slow to communicate an appreciable amount of energy to the surrounding ether. This will first become appreciable when the angular velocity increases to the order of about 10^{13}.

Orientation can evidently have no effect on the change of frequency caused by rotation. Hence the radiation from a large number of aggregates will be a mere summation of the radiation from individuals, unmodified by orientation. Since each rotating radiator generates waves of two nearly equal frequencies (with or without the original mean frequency according to structure),

the radiation from a large number of radiators will consist of double or triple lines, each broadened by the variation in angular velocity of the radiators, and further broadened by the Doppler effect of translation when this is relatively great. As the mean velocity of rotation is increased, the components of the doublet or triplet will broaden and move farther and farther apart according to the law expressed by (8).

If then, the structure of a molecule be such that its angular velocity or the angular velocity of its component atoms be large in proportion to its linear velocity, the spectrum lines emitted will double or triple when faint, and continue so with broadening and separating components as the excitation is increased, until reversal occurs on account of the non-homogeneity of the source (Figs. 3 and 4). The lines of the iron spectrum are typical of this behavior. If, on the other hand, the angular velocity is small compared with the linear velocity, the Doppler broadening will mask the doubling caused by rotation, and lines will remain single until reversal proper occurs (Figs. 1, 2, and 5). In this case the effect of rotation will be to broaden the upper part of the emission wave-length curve,

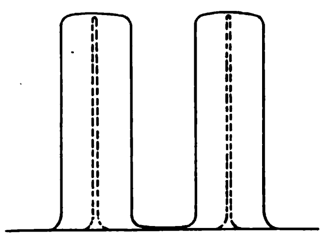


FIG. 4

Dotted line—effect of pure rotation.
Solid line—effect of rotation and translation.

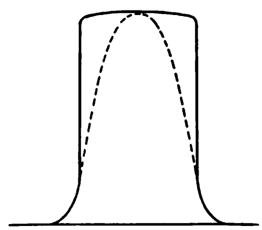


FIG. 5

Dotted line—effect of pure translation.
Solid line—effect of translation and rotation.

to change it from the inverted Λ to the inverted ∩ type. Fig. 1 shows the type of line structure corresponding to an angular velocity negligibly small in comparison with the linear velocity. Fig. 3 shows the opposite extreme corresponding to large angular and small linear velocity. Comparing the broadening with the doubling, we see that doubling will be apparent when the expression $\omega V:up$ $(=2\pi\lambda\omega:u)$ is large compared with unity, while a line will broaden without doubling when this is small compared with unity.

Since they develop as depicted in Fig. 1, it would appear that the lines of the sodium group come from atoms or molecules having a relatively small angular velocity, while for the iron and platinum group the angular velocity is large. If these deductions are correct, spectroscopy may supply valuable data for the kinetic theory of gases and the theory of magnetism.

Bureau of Standards,
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AN ATTEMPT TO FIND THE CAUSE OF THE WIDTH AND OF THE PRESSURE-SHIFT OF SPECTRUM LINES

By W. J. HUMPHREYS

The widths of all spectrum lines and the wave-lengths certainly of many are both functions of the pressure surrounding the luminous source, and the following is an attempt to develop a working hypothesis for the explanation of these phenomena.

Many spectrum lines yield the well-known Zeeman effect when their source is in a magnetic field, and therefore we conclude that the particles producing these lines have, at least while luminous, magnetic fields of their own. The nature and the magnitude of this phenomenon indicate that the radiations and the magnetic fields are due to moving electrons of the cathode type, and it is convenient, in discussing the Zeeman effect, to regard these electrons as revolving in closed orbits.

While such an assumption seemed desirable, it was necessary to give it proper limitations, to find a structure meeting these conditions that would not violate known physical laws; and this problem has been solved by J. J. Thomson,[1] who has shown that an atom consisting of negative electrons in a sphere of uniformly distributed positive electricity is stable when the electrons are properly spaced and rapidly rotating in coaxial circular orbits, the axis of rotation passing through the center of the atom, and the number of electrons per orbit increasing with the order of its distance from the center. When undisturbed the angular distance, as seen from a point on the axis, from electron to electron of any given ring is a constant.

Clearly, if the electrons are revolving in circular orbits, each ring will produce its own magnetic field, and therefore the system will possess minimum potential energy when the planes of the rings are parallel and all the electrons are rotating in the same direction. I therefore assume that this is the general distribution and condi-

[1] *Philosophical Magazine*, (6) 7, 237–265, March 1904.

tion of the electrons in an atom. As to the equal amount of positive electricity, it is only necessary that it shall be approximately at rest with reference to the electrons, and so distributed as to secure the stability of the rings. This may be secured, as above explained, by having it uniformly distributed throughout a sphere whose center is on the axis of the rings, and whose radius is equal to or greater than that of the outermost orbit. Possibly the same result would follow if the positive electricity was uniformly distributed throughout an ellipsoid of revolution whose equatorial plane was parallel to the planes of the orbits. But it is sufficient to know that the ring system of negative electrons is possible.

I assume that the frequency of the electromagnetic or light waves given off by any ring of electrons is either the same as the frequency of its orbital revolution, or else directly dependent thereon. For calculations the former will be used. I assume further that the frequency of this orbital revolution is not appreciably, if at all, a function of the kinetic energy of the atom as a whole—that it is practically free from temperature changes. This may seem to violate certain teachings in the kinetic theory of gases, but practically the same contention has been made by J. J. Thomson,[1] who says:

> If the kinetic energy arising from the motion of the corpuscles relatively to the center of gravity of the atom could by collisions be transformed into kinetic energy due to the motion of the atom as a whole, i. e., into molecular temperature, it would follow from the kinetic theory of gases, since the number of corpuscles in the atom is exceedingly large, that the specific heat of a gas at constant pressure would be very nearly equal to the specific heat at constant volume; whereas, as a matter of fact, in no gas is there any approach to equality in these specific heats. We conclude, therefore, that it is not by collisions that the kinetic energy of the corpuscles is diminished.

In connection with this question see also Magie, "The Partition of Energy," *Science*, N. S., **23**, 168 *et seq.* Besides, if it is granted that spectrum lines depend for their origin upon orbital rotations of electrons, and the frequency of these in turn upon the temperature of the gas, then their wave-lengths and the magnitude of the Zeeman effect should be corresponding functions of the temperature; but such a relation does not appear to exist.

[1] *Electricity and Matter*, pp. 98, 101, 104, and 105.

Again, probably the existence of magnetism in a piece of metal owes its origin to Ampere currents in the form of permanently rotating rings of electrons. If so, then no temperature, however low, has stopped this rotation.

Consider now some of the mutual actions of this type of atom upon each other when in a gaseous condition; to be specific, say iron atoms in the electric arc, at atmospheric pressure.

The best available sources give for iron atoms, under the specified conditions, the following data:

Average velocity of each atom as a whole, 10^5 cm per second.

Charge of each electron, 10^{-20}, in electromagnetic measure.

Charge of each electron, $3 \cdot 10^{-10}$, in electrostatic measure.

Total number of electrons per iron atom $5 \cdot 10^4$.

Mass of each electron 10^{-27} gram.

Mass of iron atom $5 \cdot 10^{-23}$ gram.

Radius of atom, equal to or greater than radius of outer ring of electrons, 10^{-8} cm.

Average distance between centers of atoms, $6 \cdot 10^{-7}$ cm.

Assumed number of orbital revolutions per second, inversely proportional to the wave-length; 10^{15} for λ 3000, $5 \cdot 10^{14}$ for λ 6000.

This angular velocity does not seem to be at all prohibitively great. The "centrifugal force" on a single electron is equal to $m\omega^2 r$, where m is its mass, ω its angular velocity, and r the radius of its orbit; while the force with which it is drawn by the positive charge toward the center of the atom is equal to $\frac{e^2 5 \cdot 10^4 r}{a^3}$, where e is the electrostatic charge on each electron, and a the radius of the atom. The ratio of these two forces is independent of the radius of the electron orbit, and, with the attraction for the numerator, is equal to $2 \cdot 10^7$. Consequently the electron rings might have angular velocities of the order assumed, and still be in no danger of flying to pieces.

From the above data it is easy to calculate approximately the magnetic force at the center of the atoms, but to further simplify the work it will be assumed that the several rings of electrons are coplanar and concentric with the atom.

Let i_k be the average current, in absolute electromagnetic meas-

ure in the ring K, then $i_k = \frac{Q_k}{t}$, where Q_k is the total quantity of electricity passing any point on the orbit in the time t.

Let ω_k be the constant angular velocity, then $i_k = n_k 10^{-20} \frac{\omega_k}{2\pi}$, where n_k is the number of electrons in the ring K. Let the radius of this ring be r_k, then the magnetic force at its center is

$$H_k = \frac{n_k 10^{-20} \omega_k}{r_k} .$$

Therefore the entire system of orbits gives at the center of the atom a magnetic force

$$\Sigma H_k = \Sigma \frac{n_k 10^{-20} \omega_k}{r_k} .$$

But for λ 6000, $\omega = \pi 10^{15}$, probably somewhat less than the average, though of the same order, while the radius of the outer ring is not greater than 10^{-8} cm, and the radii of the others still less. It therefore would seem conservative to let the average angular velocity be $\pi 10^{15}$, and the average radius 10^{-8} cm. In this case the magnetic force at the center of iron atoms is

$$H = \frac{5 \cdot 10^4 10^{-20} \pi 10^{15}}{10^{-8}} = 5\pi 10^7 .$$

According to the above conception of the structure and behavior of atoms, the greater the atomic weight, the greater the strength of the magnetic field, though not necessarily in exactly the same ratio.

It may also be worth while to note that the gyroscopic action of the whirling electrons will tend to cause an atom, when it moves about, to keep its axis always pointing in the same direction, and that the greater the atomic weight, the greater will this tendency be. However, in the turmoil of an electric arc, the direction of an atom's axis is likely to change both rapidly and frequently.

The magnetic fields of such atoms as are here considered are still powerful at appreciable distances from the atoms themselves. Let r be the radius of the orbit, d its distance from a point p on its axis; then the magnetic force at this point, along the axis, is, for iron atoms,

$$H = 5\pi 10^7 \frac{r^3}{d^3} .$$

If the distance is ten times the radius, the force is $5\pi 10^4$, or threefold the most intense field yet obtained by means of an electromagnet. Even at the average distance of the nearest atom, that is, $6 \cdot 10^{-7}$ cm, $H = 730$. Of course, the direction and the magnitude of this force is determinate for any point on or off the axis, but for the purpose of this paper the simple case of points on the axis is sufficient.

With velocities of 10^5 cm per second each atom will very often approach and leave other atoms. The magnitude of their relative velocities and the angle between the planes of the electron orbits both will vary through wide ranges, but in general at every approach and recession each atom will produce an induced current in the other of greater or less magnitude.

Consider the case of two atoms on a common axis. When their electrons rotate in the same direction, an approach will induce in each atom an electromotive force that will oppose the existing current, and as the atoms recede the induced electromotive force in each will be with the current. If, however, the electrons are rotating in opposite directions, the results will be just the reverse; that is, the induced electromotive force will be with the currents as the atoms approach, and against the currents as they leave each other. In the first case, where the electrons rotate in the same direction, the currents will decrease as the atoms approach, and then increase as they recede, coming finally to their original undisturbed values. In the second case they first increase, then decrease till again undisturbed values are reached. In the first case the currents are always less, in the second always greater, than they are in the undisturbed atom.

In the case of an induced current,

$$E = L\frac{di}{dt} + Ri ,$$

where E is the induced electromotive force, L the self-induction of the circuit, $\frac{di}{dt}$ the rate of change of the current, R the ohmic resistance of the circuit, and i the strength of the current.

But when, as in the present case, the circuit consists of a single turn, $E = \frac{dN}{dt}$ is the rate of change of the lines of magnetic force

inside the circuit. Therefore for the ring K, if its self-induction remains constant, the equation becomes,

$$\frac{dN_k}{dt}=L_k\frac{di_k}{dt}+R_k i_k\ .$$

But $R_k=0$, since the electrons meet with no ohmic resistance in their orbits, and as the dt on one side of the equation is identical with the dt on the other, therefore

$$di_k=\frac{dN_k}{L_k}\ .$$

Thus the induced current is at all times directly proportional to the total change in the number of magnetic lines of force passing through the circuit. Besides, every induced current persists so long as the new number of lines of magnetic force through the circuit is not allowed to change. In the case of any particular ring K, the value of the current is

$$i_k=\frac{n_k 10^{-20}\omega_k}{2\pi}\ .$$

Hence $di_k=\frac{n_k 10^{-20}d\omega_k}{2\pi}=\frac{dN_k}{L_k}$, which shows that $\frac{d\omega_k}{dN_k}$ is a constant. Therefore, if the period of a light vibration is the same as the period of orbital rotation of the electrons, or directly dependent upon it, then, whatever the magnitude of the Zeeman effect on a given line, this effect should not be momentary, but should persist invariable so long as the field is unchanged, which, as we know, agrees with the observations.

Again, if the change of the magnetic field does not change the self-induction of the circuit—does not change the radii of the orbits—then the change in ω, the magnitude of the Zeeman effect, should be directly proportional to the strength of the magnetic field, which also is in agreement with observation.

That only the angular velocity, and not the orbital radius, varies when the magnetic field is changed has been demonstrated very cleverly by Langevin.[1] The importance of this proof, I trust, will justify the following slightly modified reproduction of it.

$$M=iA=\frac{ne\omega r\pi r^2}{2\pi r}=\frac{ne\omega r^2}{2}\ , \tag{1}$$

[1] *Journal de Physique*, (4) 4, 678–692, October 1905.

where M is the moment of the magnetic shell equivalent to the given ring, A its area, i the current, e the charge of a single electron, n the number of electrons in the ring, ω its angular velocity, and r its radius.

Let the external magnetic force, normal to the plane of the electron orbit, be changed at a uniform rate by an amount H. This will inductively change the value of the current by acting tangentially along the ring on each electron with a force Fe, so that the moment of the entire force on the ring becomes $Fner$. But if m is the mass of each electron, then the moment of the total tangential force may be written

$$2mn\frac{d}{dt}\left(\frac{\omega r^2}{2}\right).$$

Therefore

$$Fner=2mn\frac{d}{dt}\left(\frac{\omega r^2}{2}\right).$$

From (1) $\frac{dM}{dt}=ne\frac{d}{dt}\left(\frac{\omega r^2}{2}\right)=\frac{Fne^2r}{2m}$. Hence $dM=ned\left(\frac{\omega r^2}{2}\right)$.

But ds on the orbit $=\omega r dt$, and therefore

$$dM=\frac{Fne^2ds}{2m\omega}.$$

Let δM be the minute change in moment during one orbital revolution. ω will remain practically constant during this short time, and therefore

$$\delta M=-\frac{ne^2}{2m\omega}\int_0^{2\pi r}Fds\,, \quad \text{very nearly.}$$

But the integration of an electric force around any closed circuit is equal to the rate of change of the lines of magnetic force in the circuit. Therefore $-\int_0^{2\pi r}Fds=\frac{dHA}{dt}=\frac{\delta HA}{\tau}$, where δHA is the change in magnetic flux through the circuit during the periodic time τ. Consequently

$$\Delta M=-\frac{ne^2HA}{2m\omega\tau}=-\frac{ne^2HA}{4\pi m}.$$

In the case of a mass m rotating uniformly in a circular orbit

under a central force $f(r)$, we have, when it is free from external disturbance,

$$f(r)=m\omega^2 r\ .$$

Now let a magnetic field of intensity H be established normal to the plane of rotation. This will give an added central force $He\omega r$ to each electron. As a result, suppose both r and ω to be slightly changed, giving

$$f(r+\Delta r)=m(\omega+\Delta\omega)^2(r+\Delta r)+He\omega r\ .$$

Therefore

$$[f'(r)-m\omega^2]\Delta r=2m\omega r\Delta\omega+He\omega r\ ,\quad \text{nearly.} \tag{2}$$

As shown above, $dM=ned\left(\frac{\omega r^2}{2}\right)$, or for a single electron

$$\Delta M=e\Delta\left(\frac{\omega r^2}{2}\right)=-\frac{e^2HA}{4\pi m}\ .$$

But

$$A=\pi r^2\ ,$$

hence

$$\frac{\Delta\omega r^2}{2}=-\frac{eHr^2}{4m}\ .$$

Also

$$\frac{\Delta\omega r^2}{2}=r\omega\Delta r+\frac{r^2\Delta\omega}{2}\ .$$

Therefore

$$-r\omega\Delta r=\frac{r^2\Delta\omega}{2}+\frac{eHr^2}{4m}\ ,$$

and

$$-4m\omega^2\Delta r=2m\omega r\Delta\omega+He\omega r\ . \tag{3}$$

Subtracting (3) from (2), we get

$$[f'(r)+3m\omega^2]\Delta r=0\ ;$$

hence either $\Delta r=0$, or $f'(r)+3m\omega^2=0$.

If $\Delta r=0$, then from (3) $\Delta\omega=-\frac{He}{2m}$.

If, however, Δr is not zero, then $f'(r)+3m\omega^2=0$, which, combined with $f(r)$, gives $\frac{f'(r)}{f(r)}=-\frac{3}{r}$, and $f(r)=\frac{C}{r^3}$. That is, the only central force that will allow r to change is the improbable one that varies inversely as the cube of the distance. From this it would appear that r almost certainly does not appreciably change as the strength of the magnetic field is varied. If r is constant,

it follows that the self-induction is also constant, and the expressions obtained above for the induced currents are justified.

In discussing the motions of atoms among each other, it is necessary to take into consideration not only the effects of temperature, but also the results of their mutual magnetic and electrical attractions and repulsions. But each atom may be regarded as a negative ring with a positive center (center of the positive sphere) of equal amount, and therefore, at distances large with reference to the atomic radius, the resultant electrical force of one atom upon another is practically zero; but with this distance sufficiently decreased, the resultant force (repulsion) is relatively very large. That is, the electrical field of a neutral atom is practically zero everywhere except in the immediate neighborhood of the atom itself.

If u is the velocity of an electron in its ring, then the strength of the magnetic field which it produces at the point r, θ, is $\frac{eu}{r^2}\sin\theta$, and the magnetic attraction between two such moving electrons, provided their velocity does not approach that of light, is $\left(\frac{eu}{r}\right)^2\sin\theta\cos a$, where a is the angle between their directions. But the electrostatic repulsion, under the same conditions, between these electrons is $\left(\frac{e}{r}\right)^2$. In the first case e is in electromagnetic measure, in the second in electrostatic, and the ratio between these is V, the velocity of light. Therefore even in the most favorable case, where $\sin\theta$ and $\cos a$ are both equal to unity, the repulsion is greater than the attraction in the ratio of the square of the velocity of light to the square of the velocity of the electrons. But the velocity of the electrons is roughly $\pi 10^{-8} 10^{15}$ cm per second, or one six-hundredth that of light; and consequently, if the rings existed alone, their repulsion would greatly exceed their attraction. However, owing to the structure of the atom, as explained above, the total repulsion probably does not exceed the attraction, under most favorable conditions, except when the atoms are exceedingly close together. Of course, each force produces its own effect, independent of all the others, and therefore may be considered alone.

Take the very special but simple case of two atoms whose electrons are revolving around a common axis, and let the direction

of their planes remain fixed, just as the gyroscopic action of the whirling electrons tends to keep them. In this case, whatever the magnitude of the electrostatic action and of the temperature velocity, both will be independent of the direction of the electron rotation. The magnetic force, however, will be attraction when the directions of rotation are the same, and repulsion when they are opposite. It therefore becomes desirable to calculate the approximate velocity the magnetic force can give the atoms during the short time any two can remain sufficiently close together.

As already shown, the force at a point p on the axis distant d from the electron ring is

$$H=\frac{2\pi ir^2}{d^3}=\frac{2\pi ir^2}{(r^2+x^2)^{3/2}},$$

where x is the distance of p from the center of rotation. Let the plane of the second atom pass through p, then, if the field is uniform, the magnetic flux through the second circuit due to the first is

$$\frac{2\pi^2 ir^4}{(r^2+x^2)^{3/2}},$$

and the force between the two circuits is equal to the current in the second multiplied by the differential of the magnetic flux through it with respect to the distance separating them, which gives, when the atoms attract each other,

$$F=2\pi^2 i^2 r^4 \frac{d}{dx}\frac{1}{(r^2+x^2)^{3/2}}=-\frac{6\pi^2 i^2 r^4 x}{(r^2+x^2)^{5/2}}.$$

Applying this equation to the case of two iron atoms, the distance between whose centers is $10r$, we get

$$F=\frac{6\pi^2(25\cdot 10^{-2})^2(10^{-8})^4 10^{-7}}{[(10^{-8})^2+(10^{-7})^2]^{5/2}}=375\cdot 10^{-6}\text{ dyne}.$$

But the mass of an iron atom is $5\cdot 10^{-23}$ gram. Therefore, if one atom is kept stationary and the other allowed to move under the magnetic force at this distance, its acceleration will be $375\cdot 10^{-6}$ cm per second. Now let one atom be stationary and let another pass by it with the average velocity of 10^5 cm per second. Let the planes of their orbits be parallel and separated, at their nearest approach, by ten times the radius, and suppose the magnetic force to act while a distance of only three times the diameter is passed over.

The time required to travel this distance of $6 \cdot 10^{-8}$ cm is $6 \cdot 10^{-13}$ seconds, and in this time the velocity generated, due to the magnetic action alone, is $45 \cdot 10^5$ cm per second, or forty-five times the average temperature velocity. Both atoms will be acted on simultaneously, and hence their relative acceleration will be doubled. It is likely that no such great velocities would be generated under the supposed conditions, because every increase in the velocity will correspondingly decrease the period during which acceleration can take place. However, it is clear that the line-of-sight motion of such atoms will, when they are close together, be greatly different from that due to temperature alone. Besides, they certainly will act inductively upon each other, and with distinctly greater effect when they attract, thus getting into the stronger portions of each other's magnetic fields, than when the reverse is the case.

The relative velocities and orientation of the atoms will vary through wide ranges, but from the conclusions reached in the above discussion it appears that atoms can not easily, if at all, be forced into actual contact, owing to the large electrostatic forces that come into play, and that therefore when they rush close together they will rebound; also that, owing to their powerful magnetic fields, they will pursue paths that bring mutually attracting faces relatively close together, and keep the repelling ones comparatively far apart.

From these considerations certain general deductions may be made in regard to spectroscopic phenomena.

I. Only neutral atoms and positive ions—that is, atoms less one or more electrons—can give spectrum lines. The forces acting on these two classes would not be the same, and the lines themselves might therefore radically differ, as Stark[1] has shown them to. Free electrons could be expected to produce only electromagnetic pulses (Roentgen rays) as a result of their more or less sudden accelerations.

II. When a luminous gas is very attenuated, so that any given atom spends much the greater portion of its existence away from the influence of other atoms, then its spectrum lines will be nar-

[1] *Physikalische Zeitschrift*, **25**, 892, 1905.

rowest; such widths as they do have will be due to motion in the line of sight.

Neglecting collisions, we get the approximate result very simply. Let λ be the wave-length when there is no motion, λ_1 its modified value produced by line-of-sight velocity. Then $\lambda - \lambda_1 \equiv \delta\lambda = \frac{\lambda v \cos\theta}{V}$, where v is the velocity of the particle (observer stationary), V the velocity of light, θ the angle between the path of the particle and the line of sight and having all values from o to π. But $v = k\sqrt{\frac{T}{m}}$, where T is absolute temperature, m the mass of the luminous particle, and k a constant. Therefore

$$\delta\lambda = \frac{\lambda k \sqrt{T} \cos\theta}{V\sqrt{m}}.$$

That is, the spreading will be:

1. Symmetrical about the point of maximum intensity.
2. Proportional to the wave-length.
3. Proportional to the square root of the absolute temperature directly.
4. Proportional to the square root of the atomic weight inversely.

III. When the density becomes more and more pronounced, a correspondingly increased proportion of light will be produced while the atoms are close enough markedly to affect each other. There will then be three causes of broadening:

a) The temperature line-of-sight motion.

b) The line-of-sight motion due to the attractions and repulsions of the atoms—probably in many cases *b*) exceeds *a*).

c) The mutually induced currents in the atoms.

Both *a*) and *b*) will produce symmetrical broadening, but *c*), owing to the fact that its effect is greatest when the atoms are arranged so as to attract each other (the atoms then getting much closer together and producing correspondingly greater mutual inductions), will cause unsymmetrical broadening; the bulk of the spreading due to this cause being toward the side of longer wave-length.

Among the spectroscopic phenomena, therefore, which a dense gas may be expected to give are the following:

1. All lines should increase in width when the pressure about their source is increased.

2. With increase of pressure the maxima of all lines should shift toward the red end of the spectrum. (This is a general statement, possible exceptions will be mentioned below.)

3. Ordinarily the spreading of a line should be much greater than its pressure displacement, though with a short exposure it may appear on a negative as a displaced narrow line.

4. Since the intensity of a magnetic field due to a circular current varies inversely as the cube of the distance from it, while the average distance between the molecules of a gas (supposed monatomic in the electric arc) varies directly as the cube root of the pressure, therefore the spreading and the shift both should be roughly linear functions of the pressure. That is, they should increase approximately as the average mutual disturbing influence of the atoms, or as the intensities of those parts of each other's magnetic fields in which they exist.

5. For lines of a given element, similar in their nature, the shifts should be proportional to the wave-length.

6. The spreading and the shifting both should obtain whatever the nature of the surrounding gas, as all atoms present are supposed to be magnetic. The shift, however, should increase as the atomic weight of the surrounding medium is increased—heavier atoms possessing stronger magnetic fields.

7. The shift of analogous lines due to different elements of the same general nature, elements of the same Mendelejeff group, should increase with increase of atomic weight, since the strength of an atom's magnetic field probably is an increasing function of atomic weight.

8. Any group of lines due to a given element, such as a series, that gives Zeeman effects proportional to the wave-length, should shift under pressure in the same ratio.

9. Ordinarily, lines of large Zeeman effects should show large pressure displacements, while those of small Zeeman effects should be little shifted.

10. Any lines, such as those of band spectra, that do not show the Zeeman effect, should not be displaced.

Every one of the above conclusions is in substantial agreement with experiment, both those applying to the width,[1] and those that refer to the pressure displacement.[2]

Probably all, or nearly all, the phenomena under I and II would follow from the assumption, which the Zeeman phenomenon appears to justify, that, whatever its structure, a radiating atom produces in its immediate neighborhood a powerful magnetic field—magnetic because it yields to a magnetic field, and powerful because the extent of the yielding is small, the change in wave-length being but a minute fraction of the whole. Therefore the structure assumed at the beginning of this article may not at all agree with real atoms; but such atoms would be magnetic, a property we know luminous atoms to have, and it admits of conception and discussion. Besides such an atom would behave spectroscopically very much as real atoms do behave, and therefore it may serve the double purpose of co-ordinating known phenomena, and of suggesting certain others that may be looked for, and how.

If atoms are assumed to consist in part of rotating rings of electrons, and the spectrum lines to be due to these rotations, then it becomes necessary to show why the rings radiate only under special conditions, and why their energy does not rapidly become dissipated in radiation.

It is assumed that each ring consists of a large number of electrons, symmetrically arranged when undisturbed. In this condition the loss of energy due to radiation, as J. J. Thomson has shown,[3] would be exceedingly minute.

If the negative electricity should entirely fill the rings, after the manner suggested by Lord Rayleigh,[4] then, when undisturbed, probably their radiation would be absolutely zero. In either case the loss of energy from radiation, and any restitution of it, from absorption, from flying electrons, or otherwise, might very well be beyond the power of known means for detection.

Let such atoms as these, non-radiating when undisturbed, be

[1] Michelson, *Astrophysical Journal*, 2, 251–263, 1895.

[2] Humphreys, *ibid.*, 6, 169–232, 1897.

[3] *Philosophical Magazine*, (6) 7, 237, 1904.

[4] *Ibid.*, (6) 11, 117, January 1906.

hurled violently among each other, as they are at high temperatures. Each will very frequently approach some other closely, and in so doing will cause and suffer inductive effects. In general these disturbances will not be symmetrically distributed about the axis of rotation, and thus greater or less bunchings of the electrons will be produced, and these in their rapid rotation will cause correspondingly powerful electromagnetic radiation—a decreasing radiation with zero for its limit; but, except for disturbances, of constant period, as the deformed rings recover their normal condition. In this way the real energy of radiation is traced back to the energy of the disturbing cause; to the temperature, or kinetic energy of the atoms, and probably in some cases to loose and flying electrons.

Atoms constituted and behaving as here considered would produce radiations corresponding to the period of each ring, and therefore, certainly in the case of elements of the same family, those of greater atomic weight may be expected to furnish the greater number of lines, as they do.

While the number of radiations could not be less than the number of rings, it might be much greater, because of the possibilities for combinations analogous to combination tones in sound; combinations which readily could lead to series of doublets and triplets in which the Zeeman effect would be the same from group to group of lines, but different between the separate lines of each group. And probably, if such lines actually exist, the Zeeman effect, the broadening, and the pressure-displacement together may lead to their identification. But whether this should be the result or not, such an investigation would be reasonably sure of valuable discoveries, for the spectroscopic field is a peculiarly rich one.

In closing, I wish to thank Dr. Ames, who has read this in the manuscript, for his interest and helpful criticisms.

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THE LUMINOSITY OF THE BRIGHTEST STARS

By GEORGE C. COMSTOCK

The prevailing opinion among astronomers admits the presence in the heavens of at least a few stars of extraordinary intrinsic brilliancy. Gill, Kapteyn, and Newcomb have under differing forms announced the probable existence of stars having a luminosity exceeding that of the Sun by ten-thousand fold or more, possibly a hundred-thousand fold, and *Canopus* is cited as an example of such a star. It is the purpose of the present article to examine the evidence upon which this doctrine is based, and the extent to which that evidence is confirmed or refuted by other considerations.

As respects *Canopus*, the case is presented by Gill, *Researches on Stellar Parallax*, substantially as follows. The measured parallaxes of this star and of *a Centauri* are respectively $0\rlap{.}''010$ and $0\rlap{.}''762$, and their stellar magnitudes are -0.96 and $+0.40$; i. e., *Canopus* is 3.50 times brighter than *a Centauri*. The light of the one star is therefore $3.50\left(\frac{0.762}{0.010}\right)^2$ times as great as that of the other. But since *a Centauri* has the same mass and the same spectrum as the Sun, and therefore presumably emits the same quantity of light, we may substitute the Sun in place of *a Centauri* in this comparison, and find from the expression given above that *Canopus* is more than 20,000 times as bright as the Sun. I have sought for other cases of a similar character, using a method slightly different from that of Gill. If we assume, as is commonly done, that in the celestial spaces the intensity of radiant energy varies inversely as the square of the distance, we may derive the following well-known relation that must exist between the luminosity, L, the parallax, π, and the stellar magnitude, m, of every star, viz.,

$$L\pi^2\rho^m = c \ . \qquad (1)$$

When the parallaxes are expressed in seconds of arc, the luminosities in terms of the Sun's output of light taken as unity, and when, in accordance with the best determinations, the logarithm of the light-ratio, ρ, is put equal to 0.4 and the Sun's stellar mag-

nitude is taken as -26.2, the constant c in the above expression becomes sensibly equal to $\sqrt{2}$. With these values I have computed for every star brighter than the second magnitude for which I have been able to find a reliable parallax determination, the resulting value of the luminosity, L, and these values will be found in Table III.

The observed parallaxes of the stars are in every case relative; i. e., they are the difference between the parallax of the star in question and those of certain fainter comparison stars. Since the π which appears in Equation (1) is an absolute parallax, we must either assume that the comparison stars are infinitely distant, or we must add to the observed relative parallax assumed values of the parallaxes of the comparison stars obtained as follows. The direction of the Sun's motion in space and the amount of that motion per annum (spectroscopically determined) being known, we may combine with these the average angular proper motion shown by stars of any given magnitude—e. g., the seventh—and obtain from the combination the average linear motion and average distance of the given group of stars. The results of investigation of this kind made by Kapteyn for stars to the ninth magnitude and extended by the present writer over an additional two magnitudes, are presented in the second column of the following short table, from which have been interpolated parallaxes of the comparison stars corresponding to the magnitudes as given by the observer.

TABLE I

Magnitude	Mean Parallax	Mean Luminosity
3.0	0.″0320	87
5.0	0.0156	58
7.0	0.0093	26
9.0	0.0063	9
11.0	0.0046	3

On the average the interpolated corrections to the observed relative parallaxes cannot be far wrong, although in any particular case they may be either too great or too small. Since the comparison stars are rarely brighter than the seventh magnitude, these corrections are always less than 0.″01, and since the true parallax

of the comparison star cannot be less than 0."00, we are assured that in no case will the correction make the resulting absolute parallax of the principal star too great by so much as 0."01. On the other hand, the true parallax of the comparison star may exceed the tabular value by several, or many, hundredths of a second, and probably will thus exceed it in some cases, producing a corresponding error of defect in the resulting parallax of the principal star. As a result, Table III contains no case in which the adopted parallax has been made so much as 0."01 too great in the transition from relative to absolute parallaxes. It may, and probably does, contain cases in which the adopted value has been made several hundredths too small.

To render more precise the conditions of our search for evidence that there exist stars of extraordinary brilliancy, I adopt as the definition of such stars that they shall emit 1,000 times as much light as the Sun, and, introducing into Equation (1) the value $L=1{,}000$, find the following values of the absolute parallax of such a star corresponding to the magnitudes, m, shown in the following table.

TABLE II

L	m	π
1000	2.0	0."015
1000	3.0	0.009
1000	4.0	0.006
1000	5.0	0.004

Below the second magnitude these absolute parallaxes corresponding to $L=1000$ are not greater than the mean parallaxes of the comparison stars commonly employed, and therefore if there are such very bright stars, apparently fainter than the second magnitude, their relative parallaxes are approximately zero and indistinguishable from errors of observation. Table III therefore contains all the obtainable data for our quest, and in considering these data we find at once four inadmissible cases. The negative absolute parallaxes are clearly impossible and show only the presence of sensible errors of unknown amount. We may conjecture that the luminosities of these four stars are greater than the average, but how much

greater is quite unknown, and the stars must be dropped from consideration as unavailable for the present purpose.

TABLE III

Star	Mag.	Parallax	Lum.	Star	Mag.	Parallax	Lum.
α Eridani	0.5	0.050	355	*β Crucis*	1.5	0.004	30
α Persei	1.9	0.076	43	*ε Ursae Majoris*	1.8	0.088	22400
α Tauri	1.2	0.117	34	*Spica*	1.4	−0.012	.....
Capella	0.2	0.088	151	*η Ursae Majoris*	1.9	−0.042	.....
Rigel	0.5	0.008	13800	*β Centauri*	1.2	0.054	160
β Tauri	1.8	0.067	60	*Arcturus*	0.3	0.033	996
α Orionis	1.2	0.031	490	*α²Centauri*	0.4	0.758	2
Canopus	−1.0	0.008	54950	*Antares*	1.2	0.030	525
γ Geminorum	1.9	−0.012	.....	*Vega*	0.4	0.090	120
Sirius	−1.3	0.376	33	*Altair*	1.1	0.240	1
Castor	2.0	0.028	288	*α Cygni*	1.6	−0.003	.....
Procyon	0.7	0.342	6	*α Gruis*	1.9	0.023	456
Pollux	1.5	0.064	87	*α Piscis Austrinus*	1.4	0.137	21
Regulus	1.8	0.032	263				
α Ursae Majoris	2.0	0.058	66	Mean	1.10	0.″0962	3820
α Crucis	1.0	0.057	173				

There remain three stars to which the data assign extraordinary brilliancy as defined above, and possibly to these should be added *Arcturus*, whose luminosity comes just within the limit. To test the character of the evidence that they afford, we form the mean of the numbers in the luminosity column, and find that on the average the twenty-five stars under consideration are individually 3820 times as bright as the Sun.

Two circumstances tend to impair confidence in this value:

a) Twenty-two of the twenty-five stars have luminosities much less than the mean value, while three have values much greater than the mean. This distribution of values, improbable in itself, corresponds entirely to what has been above indicated as a probable result of the transition from relative to absolute parallaxes. A few parallaxes have been left decidedly too small, and have produced correspondingly great values of the luminosity.

b) The mean value itself, 3820, is far too great, and is made too great by the three abnormal cases. In the last column of Table I there is shown the mean luminosity of stars of the third, fifth, seventh magnitude, etc., computed from the mean parallaxes by means of Equation (1). Without necessarily attributing a high

degree of accuracy to these results, we cannot impugn their substantial value without overturning the foundations upon which rest the parallaxes and luminosities of Table III. We regard them therefore as furnishing at least a rough indication of the order of brilliancy of these stars, showing, as they ought, a progressive increase of luminosity with increasing apparent brilliancy. Through a graphical process I have extrapolated from these data a value of the luminosity for the magnitude 1.0, corresponding approximately with the mean magnitude of Table III, and find $L=135$. On account of its non-linear character, Equation (1) is not strictly applicable to the mean relation between parallax and luminosity in a group of stars, and on this account the values of L in Table III are probably somewhat too small. On the other hand, the absorption of light in its transmission through space affects the apparent luminosity of the faint stars more than that of the bright ones, and on this account the extrapolated value of L is made relatively too great. It is not feasible, at present, to evaluate the resultant total error in the concluded luminosity of the first-magnitude stars, but whatever reasonable margin of uncertainty may be attributed to the result found above, $L=135$, it remains absolutely inconsistent with the mean value, 3820, found from Table III, while it accords fairly well with the mean, 198, of all values save the three that are otherwise suspicious. The agreement is still better if *Arcturus* be dropped from the list.

If we inquire what error must be attributed to the adopted parallaxes of three suspected stars in order to remove the abnormal character from their computed luminosities and reduce these below the limit 1000, we find the following results:

β Crucis	0".015
Rigel	0.022
Canopus	0.052

The assumption that errors of this magnitude are inadmissible either in the adopted parallaxes of the comparison stars, or in the observed relative parallaxes of the three stars named, or through a combination of both sources, constitutes the entire evidence that there exists in the heavens any star whose brilliancy exceeds that

of the Sun a thousand-fold. Opposed to it stand the considerations above designated (*a*) and (*b*), and in the judgment of the author they are of preponderant weight.

Kapteyn has investigated the luminosities of the fixed stars in a paper issued as No. 11 of the Groningen *Publications*, and there embodies a part of his conclusions in the following remarkable statement: "There will be in a space which contains 2,000,000 stars of the same luminosity as that of the Sun, 1 star with 100,000 times greater luminosity than that of the Sun," 38 stars with 10,000 times greater luminosity, 1800 stars with 1,000 times greater luminosity, etc., together with more than 12,000,000 stars of smaller luminosity than the Sun. These results appear to the present writer incredible. They are consequences, and, in so far as relates to the brightest stars, extrapolations, from an arbitrarily assumed law of the distribution of stars in space—a law in support of which no evidence is adduced beyond the statement, "the best thing further to admit seems to suppose that the quantities *z* . . . . are distributed in accordance with the law of error." The assumption thus made leads to the conclusion that the stellar density, the number of stars per unit of volume, is a minimum in the region adjacent to the Sun, increases rapidly to a maximum at the average distance of stars of the fourth or fifth magnitude, and thereafter diminishes slowly to the supposed limits of the stellar system. Recognizing the improbability of such a variation of stellar density, Kapteyn endeavors to remove it by a suitable choice of constant coefficients in his equations, but with no considerable success. The result is inherent in his fundamental assumption, and in view of the entire lack of support for this assumption and its improbable consequences, it does not seem necessary to give to the conclusions quoted above any greater measure of credence than Kapteyn himself assigns to the assumed law from which they are derived: "I need not say that I do not take the supposition made here for an expression of the truth. I am only of opinion that by making it we may expect to get a good step beyond what may be reached by simply attributing one and the same parallax to stars of a determined magnitude and proper motion."[1]

[1] *Pub. Groningen*, No. 8, p. 21.

Upon a survey of the whole case the author is unable to find any adequate evidence that the maximum of stellar luminosity requires more than three figures for its expression. He is further of opinion that the mean luminosity of the first-magnitude stars cannot be represented by a number with less than three significant figures.

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Minor Contributions and Notes.

DETERMINATION OF RADIAL MOTIONS BY OBJECTIVE-PRISMS

In Harvard *Circular* No. 13 a method is described for determining the radial motions of stars from spectra obtained with objective-prisms. As this method has recently been criticised, it may be well to describe some recent results obtained here with the Draper telescopes. A photograph is taken in the usual way, the prism is then turned 180°, and a second exposure is given on the same plate. It is not necessary or advisable to use two plates, as recommended in *Circular* No. 13. It is often more convenient to reverse the telescope, instead of turning the prism. In the latter case the plate must also be turned 180°. The second images should be brought side by side with the first, and as near together as possible. It may be better to place the spectra end to end. They may be brought into any desired position by the aid of a ground-glass screen, or more precisely by an eyepiece with cross-hairs. Were there no errors, it would be necessary only to measure the distance apart of the corresponding lines of each pair of spectra. Each star whose radial motion was known would serve to determine the constant distance apart of the lines. The differences in distance, converted into wave-lengths, would give the required motions of the other stars. The motions of the Sun and Earth are eliminated, since they are the same for all. The principal sources for error, such as those due to the distortion of the lens and changes of temperature, are radial, and may be determined, using both co-ordinates of the lines in all the spectra. Changes in the differential refraction may be reduced, if desired, by turning the prism so that the spectra shall be horizontal, instead of vertical.

Fig. 1 was obtained from a contact print of a negative representing the *Pleiades*. It was taken on January 29, 1906, with the 11-inch Draper telescope. The scale is 52'.6=0.1 cm, and the exposures were 37 minutes and 30 minutes, respectively. These conditions are by no means ideal, but the dispersion is such, for the central portions of the spectra, that 1″ corresponds to an approach or recession of the star of about 70 km in each spectrum. Since double the motion is measured, if positions

[1] *Harvard College Observatory Circular* No. 110.

can be determined with the accuracy of $\pm 0\overset{\prime}{.}1$, which many astronomers claim is not a high degree of precision for determining star places, the corresponding probable error in the motion would be ± 3.5 km. About a dozen stars could be measured on this photograph, the brightest,

FIG. 1

η Tauri, having a magnitude of 3.0, and the faintest, 6.0. In this photograph the images are some distance apart. It is intended to illustrate the method, but not for actual measurement.

Another photograph, taken with the 8-inch Draper telescope on January 29, 1906, with exposures of 20^m, covers a region 10° square, with

the *Pleiades* as a center. The dispersion is about one-third of that in Fig. 1, but as the scale is also about one-third, the definition is much better, and measures might have nearly the same degree of precision. Much fainter stars are shown on the latter plate, lines being clearly defined in stars of the eighth magnitude. For this reason, and owing to the extent of the region covered, the number of stars measurable exceeds a hundred, but many of these could probably be used only to determine the corrections, since the distortion is large near the edges of the plate, owing to the distance from the center.

EDWARD C. PICKERING.

FEBRUARY 9, 1906.

STARS HAVING PECULIAR SPECTRA. THIRTEEN NEW VARIABLE STARS[1]

The examination of the later photographs of the Henry Draper Memorial, by Mrs. Fleming, has led to the discovery of a number of variable stars and other objects having peculiar spectra. A list of these is given in Table I, together with two additional variables found by the examination of chart plates, one by Miss E. F. Leland and one by Miss S. E. Breslin. The constellation and number in the *Durchmusterung* are given in the first two columns. The approximate right ascension and declination for 1900 and the catalogue magnitude, except in the case of variable stars, are given in the third, fourth, and fifth columns. The catalogue designations are taken from the *Bonn Durchmusterung*, except in the case of $-59^\circ.233$, which is taken from the *Cape Photographic Durchmusterung*. The class of spectrum and a brief description of the object are given in the sixth and seventh columns. Each of the new variables has been confirmed independently by Miss L. D. Wells, unless otherwise specified. Additional information regarding these objects is given in the remarks following the table. In the case of new variable stars, the right ascension is followed by the designation described in the *Annals*, **48**, 93, which gives the approximate position, and also the designation described in the *Annals*, **53**, No. 7, which indicates the number in the series of variables found at Harvard. This last number is also given in the table, for convenience of future reference.

A photograph of the variable star, *R Cygni*, taken with the 8-inch Draper telescope on November 19, 1890, shows the spectrum of this star as Class Md, having the hydrogen lines $H\gamma$ and $H\delta$ bright. On a photograph taken with the same instrument, on December 7, 1904, the spectrum

[1] *Harvard College Observatory Circular* No. 111.

of this star appears to be of the fourth type, closely resembling Class Na, and shows no trace of bright hydrogen lines.

TABLE I

PECULIAR SPECTRA

Constellation	*B. D.* No.	R.A. 1900	Dec. 1900	Mag.	Spectrum	Description
		h m	° ′			
Cassiopeia ...	....	1 32.4	+57 39	.. ..	Pec.	Bright lines. Type V.
Horologium..	−59°233	2 45.1	−59 28	.....	Mc 5 d	Variable. H 1201.
Orion.......	+ 1°1005	5 19.6	+ 1 45	5.0	B Pec.	Hβ bright.
Auriga......	R	5 48.9	+46 6	.....	Pec.	Brig't lines. Gaseous Neb.
Gemini......	+21°1609	7 23.3	+21 7	.....	Pec.	Type IV.
Sextans......	....	10 29.9	+ 0 11	.....	....	Variable. H 1202.
Crater.......	−6°3469	11 47.6	− 7 3	.....	Mc 5 d	Variable. H 1203.
Corona......	....	15 45.2	+36 35	.....	Md	Variable. H 1204.
Draco	+54°1925	17 55.6	+54 41	.....	Md	Variable. H 1205.
Sagitta.....	....	19 15.0	+17 2	.....	Md?	Variable. H 1206.
Sagitta......	....	19 15.4	+17 5	.....	....	Variable. H 1207.
Cygnus......	....	19 23.3	+47 9	.....	Pec.	Bright lines. Type V.
Aquila.......	+12°4228	20 2.3	+12 39	.....	Md	Variable. H 1208.
Cygnus......	+36°3907	20 5.8	+36 33	5.5	B Pec.	Hβ bright.
Cygnus......	....	20 14.7	+34 3	.....	Md	Variable. H 1209.
Cygnus......	....	20 24.7	+38 17	.....	Pec.	Bright lines. Type V.
Pegasus.....	R	22 1.5	+33 1	.....	....	Variable. H 1210.
Pegasus.....	R	22 1.5	+33 1	.....	Md	Variable. H 1211.
Pegasus.....	+11°4784	22 16.6	+11 42	5.5	B Pec.	Hβ bright.
Lacerta......	....	22 41.8	+54 33	.....	Na	Type IV.
Lacerta......	+53°3033	22 51.9	+53 41	9.1	Na	Type IV.
Cassiopeia ..	+59°2683	23 10.8	+59 55	9.0	Pec.	Bright lines. Type V.
Andromeda ..	+34°4974	23 33.8	+35 13	.....	Na	Type IV. Var. H 1212.
Andromeda ..	+42°4827	23 59.5	+43 0	.....	Na	Variable. H 1213.

REMARKS

h m

1 32.4. Galactic longitude, 96° 59′. Galactic latitude, −3° 38′.

2 45.1. *024559* = H 1201. An examination of this star on eight chart plates, taken between September 27, 1895, and December 2, 1902, shows a variation of about 1 3 magnitudes. Estimates from these plates give the approximate limits, 8.1 to 9.4.

5 19.6. *Hγ* is also visible as a fine bright line superposed on a faint dark band.

5 48.9. Galactic longitude, 133°. Galactic latitude, +12°. Assuming an error of +2′.8 in declination in the *Durchmusterung*, this object identifies as +46°1067 magn. 9.5. The position given is that of the object on the photograph. No evidence of proper motion is shown from a comparison of plates taken on December 29, 1890, and January 16, 1901.

7 23.3. This object is in *N. G. C.* 2392, or identical with it. *N. G. C.* 2392 was found to have a continuous spectrum, with three bright lines, by Winlock and Peirce, on January 7, 1869. *Annals* **13**, 68. It was also found to be gaseous in 1872, by d'Arrest, *Astron. Nach.*, **79**, 193. Photographs taken with the 8-inch Draper telescope, on November 21, 1900, and November 27, 1905, show no trace of the bright lines characteristic of gaseous nebulæ, but that the spectrum resembles

the fourth type. The images on chart plates, however, are hazy as compared with those of adjacent stars, and the image on a photograph taken with the Bruce telescope on April 16, 1904, shows distinct nebulosity, especially on the preceding and southern edges.

10 29.9. 102900=H 1202. Discovered by Miss E. F. Leland, by superposition of chart plates, and confirmed by Mrs. Fleming. An examination of this star on five chart plates, taken between April 24, 1891, and February 11, 1905, shows a variation of about 1.6 magnitudes. Estimates from these plates give the approximate limits 8.9 to 10.5.

11 47.6. *114707*=H 1203. An examination of this star on twenty-two chart plates, taken between May 11, 1891, and March 6, 1905, shows a variation of about 1.0 magnitude. Estimates from these plates give the approximate limits, 8.2 to 9.2.

15 45.2. 154536=H 1204. An examination of this star on ten chart plates, taken between July 23, 1890, and May 21, 1903, shows a variation of about 3.0 magnitudes. Estimates from these plates give the approximate limits, 8.3 to 11.5.

17 55.6. 175554=H 1205. An examination of this star on forty-seven chart plates, taken between August 17, 1892, and July 12, 1905, shows a variation of at least 0.6 magnitude.

19 15.0. 191517a=H 1206. An examination of this star on ten chart plates, taken between August 19, 1896, and October 15, 1900, shows a variation of at least 2.8 magnitudes. Estimates from these plates give the approximate limits, 8.7 to<11.5.

19 15.4. 191517b=H 1207. This star was selected as comparison star *o* for 191517a. In observing the latter star, it was found by Miss S. E. Breslin to be brighter than the comparison star *n* on a plate taken on March 26, 1903. An examination of this star, by Mrs. Fleming, on ten chart plates, taken between May 1, 1900, and March 26, 1903, shows a variation of at least 0.7 magnitude. Estimates from these plates give the approximate limits 12.2 to 12.9.

19 23.3. Galactic longitude, 46° 38′. Galactic latitude, +13° 23′.

20 2.3. 200212=H 1208. An examination of this star on four chart plates, taken between September 18, 1892, and September 9, 1901, shows a variation of at least 1.7 magnitudes. Estimates from these plates give the approximate limits 9.5 to<11.2.

20 5.8. The hydrogen line $H\beta$ appears as a fine bright line centrally superposed on the dark line $H\beta$, on plates taken with the 11-inch Draper telescope on July 4 and November 4, 1905.

20 14.7. 201434=H 1209. An examination of this star on five chart plates, taken between September 9, 1893, and May 23, 1899, shows a variation of about 2.6 magnitudes. Estimates from these plates give the approximate limits, 9.9 to 12.5.

20 24.7. Galactic longitude, 45° 12′. Galactic latitude, −0° 51′.

22 1.5. 220133a=H 1210. The preceding and southern of two stars, 40″ apart, both of which are variable, and either of which might be identified as +32°.4335, magnitude 9.5. An examination of this star on sixteen chart plates, taken between December 22, 1890, and August 31, 1902, shows a variation of about 0.6 magnitude. Estimates from these plates give the approximate limits, 10.0 to 10.6.

22 1.5. 220133b = H 1211. See 220133a. An examination of this star on nine chart plates, taken between December 22, 1890, and November 23, 1900, shows a variation of about 2.4 magnitudes. Estimates from these plates give the approximate limits, 10.0 to 12.4.

22 51.9. Near the border of *Andromeda*.

23 10.8. Galactic longitude, 79° 2′. Galactic latitude, −0° 11′.

23 33.8. 233335 = H 1212. An examination of this star on five charts plates, taken between September 24, 1890, and November 29, 1899, shows a variation of more than 2.3 magnitudes. Estimates from these plates give the approximate limits, 8.2 to < 10.5.

23 59.5. 235943 = H 1213. Suspected of variability by Espin. *Astron. Nach.*, **137**, 373, and *A. J.*, **16**, 171. Discovered here, independently, from its photographic spectrum. An examination of ten chart plates, taken between October 8, 1891, and November 25, 1903, shows a variation of about 1.5 magnitudes. Estimates from these plates give the approximate limits, 8.3 to 9.8.

SPECTRA OF KNOWN VARIABLES

The spectra of a number of known variables have also been determined from Draper photographs, and are given in Table II. This contains those classified since *Circular* 98 was issued, and therefore includes a few already mentioned in the Sixtieth Annual Report of the director. They are reprinted here for convenience of reference. The first column contains the designation, and the second, the name of the variable. The third column gives the class of spectrum.

TABLE II

SPECTRA OF KNOWN VARIABLES

Desig.	Name	Spectrum	Desig.	Name	Spectrum
004533	*R R Andromedae*	Md 543	190967	*U Draconis*	Md?
042215	*W Tauri*	Mb	191350	*TZ Cygni*	Mc
063558	*S Lyncis*	Md 8	194348	*TU Cygni*	Md 6
133273	*T Ursae Minoris*	Md 6	195849	*Z Cygni*	Md 6 Pec.
153378	*S Ursae Minoris*	Md 7	200647	*SV Cygni*	Na
161138	*W Coronae*	Md 4			

Desig.	Name	Spectrum
210812	*R Equulei*	Md 5
210903	*RR Aquarii*	Md 4
220412	*T Pegasi*	Md 9
220714	*RS Pegasi*	Md 9, 8, 8
233956	*Z Cassiopeiae*	Md 7

REMARKS

042215. The spectrum of this star is given as F? in the "Provisional Catalogue of Variable Stars," *Annals*, 48, No. 3. Plate I, 33567, taken on October 25, 1905, shows the spectrum of this star as Class Mb.

153378. The spectrum of this star is given as Mc 5 d in the "Provisional Catalogue of Variable Stars," *Annals*, 48, No. 3. Plate I, 33601, taken on November 1, 1905, shows the spectrum of this star as Class Md 7.

195849. The spectrum of this star is given as Mc? in the "Provisional Catalogue of Variable Stars," ***Annals*, 48**. No. 3. Plate I, 33706, taken on November 27, 1905, shows the spectrum of this star as Class Md 6.

A photograph, A 6911, of the region whose center is in R. A. $=20^h 45^m$, Dec. $=+30^\circ.6$, was taken with the 24-inch Bruce telescope, on September 2, 1904, with an exposure of 240^m. It shows the entire region containing the nebulae *N.G.C.* 6960 and *N.G.C.* 6992. From an examination of this plate, Mrs. Fleming found that the northern and perhaps the southern ends of these nebulæ are connected by faint nebulosity forming an irregular oval. A large triangular wisp of nebulosity extends southward, from the north preceding portion of this oval, and is much more conspicuous than the neighboring nebulæ, *N.G.C.*6974 and *N.G.C.* 6979.

EDWARD C. PICKERING.

FEBRUARY 16, 1906.

THE SPECTRUM OF *NOVA AQUILAE* NO. 2

Nova Aquilae No. 2 was observed visually with the one-prism spectrograph on the night of September 5, when its magnitude was about 10.5 on the Harvard scale. At that time the spectrum was similar to that of *Nova Geminorum*, as observed by Drs. Reese and Curtis on April 1, 1903.[1] The spectrum consisted of a number of bands, the brightest of which was easily identified as H_β by means of the neighboring iron lines in the iron spark. A faint band in the region of λ 4600, and the still fainter H_γ band, could also be distinguished. A series of maxima extending from the region of H_β toward the red, giving almost the appearance of a continuous spectrum, was also observed. The seeing was poor and the image very faint, due to a great amount of smoke in the air, making the identification of the various bands (with the exception of H_β) quite difficult.

Although the *Nova* was very faint, three spectrograms of it were obtained with the one-prism spectrograph as follows.

[1] *L. O. Bulletin*, **2**, 59, 60; *Astrophysical Journal*, **18**, 299, 1903.

Plate	Date	Exposure
3986 A	1905, September 6	3 hours
3994 A	September 10	4 hours
4058 A	October 11	$3\frac{1}{2}$ hours

The plates of September 6 and 10, in the region common to the visual and photographic rays, confirm the observations of September 5. The exposure time was about right for the H_β band, and much too short for the others. The following is a brief description of the bands and their approximate wave-lengths, which were obtained by interpolation from the iron comparison lines.

H_β band: strong; limits, λ 4845–4885; edges fairly sharp.

Band at λ 4600: intensity about one-fifth that of H_β; limits not sharply defined, but approximately from λ 4590–4710; fades off gradually on both sides.

H_γ band: intensity one-tenth (or less) that of H_β; width 50–60 t.-m.; sharp minimum at λ 4345.

H_δ band: very faint; width about 70 tenth-meters.

A faint continuous spectrum extends from the region λ 4500 to that of the H_γ band. H_ϵ and the so-called nebular lines do not appear on the plates. It will be noticed that the relative photographic intensities given above are very unlike those of *Nova Geminorum* in April 1903. In the case of *Nova Aquilae No.* 2 the visual and photographic observations of the early part of September agree in showing that much of the light in the visible spectrum was concentrated in the H_β band. Visual observations of *Nova Geminorum* on April 1, 1903, gave H_β much brighter than the other bands, but the spectrograms of April 2 and following nights indicate a photographic intensity for H_β much less than that of the λ 4600 H_γ and H_δ bands. While this may be due to a real difference in the stars, some of it undoubtedly arises from the difference in sensitiveness between Cramer Crown (used by the former observers) and Seed 27 plates (used in the present case).

On account of other lines of work and very poor atmospheric conditions, it was impossible to obtain another observation of the *Nova* until October 11, at which time its magnitude was about 11.4 (Harvard scale). Visual observations on that evening showed that the H_β band had decreased very much in intensity since September 10, and was now only about as bright as the other faint bands. The spectrogram taken the same night while very badly underexposed shows also this marked decrease in intensity of the H_β band, which on this plate is as faint as the H_γ band.

The author desires to acknowledge his indebtedness to Mr. S. Albrecht for his efficient assistance in securing the above spectrograms.

J. H. MOORE.

LICK OBSERVATORY,
March 7, 1906.

A LIST OF FOUR STARS WHOSE RADIAL VELOCITIES ARE VARIABLE

The following stars have been found to have variable velocities in the line of sight:

τ *Ursae Majoris* ($\alpha = 9^h\ 2^m.7$; $\delta = +63°\ 55'$)

Plate	Date	Velocity	Measured by
1626 D	1900 January 22	− 5	Campbell
		− 3.8	Stebbins
2377 A	1902 April 15	−10	Reese
		−10.2	Stebbins
2624 E	1902 December 30	− 4	Curtis
		− 6.0	Burns
3107 F	1903 December 25	− 9.7	Moore
4181 E	1906 January 29	− 1	Moore
		− 1.5	Burns

The character of spectrum is given by Harvard as of type XII *c*. The variable velocity was suspected from the second plate and confirmed by the recent measures of Messrs. Moore and Burns.

λ *Hydrae* ($\alpha = 10^h\ 5^m.7$; $\delta = -11°\ 51'$)

Plate	Date	Velocity	Measured by
686 A	1898 March 30	+23.3	Wright
1174 D	1899 February 13	+22.9	"
1648 C	1900 February 2	+18.6	"
1660 A	February 26	+19.4	"
1671 D	March 9	+18.4	"
1675 B	March 12	+19.2	"
1682 C	March 13	+19.0	"
1694 C	March 27	+19.2	"
1977 D	December 5	+15.1	Burns
2010 D	1901 January 15	+17.4	Reese
2321 D	December 23	+21.4	"
2627 C	1902 December 31	+24.1	Burns
2706 D	1903 February 23	+22.5	"
3187 A	1904 March 31	+19.9	Brasch
		+18	Moore

The spectrum is of type K. The variation was suspected by Mr. W. H. Wright from the observations of 1898, 1899, and 1900, and confirmed by the recent measures of Mr. K. Burns.

μ Ursae Majoris ($\alpha = 10^h\ 16^m.4$; $\delta = +42°\ 0'$)

Plate	Date	Velocity	Measured by
309 A	1897 February 24	−24	Campbell
		−27.4	Burns
689 A	1898 March 31	−20	Campbell
		−22.0	Burns
1201 C	1899 March 6	−20	Campbell
		−19.1	Burns
3208 D	1904 April 11	−16	Moore
		−16.2	Burns
4151 D	1906 January 4	−23	Moore

The spectrum is of type M.

The binary character of the above three stars was discovered with the Mills spectrograph. Unfortunately the plates are not properly distributed to give an idea of the period of any of them.

Y Ophiuchi ($\alpha = 17^h\ 47^m.3$; $\delta = -6°\ 07'$)

This star was discovered to be a spectroscopic binary by Mr. S. Albrecht (Fellow in the Observatory) from a series of observations made with the one-prism spectrograph during the summer and fall of 1905. The period coincides with the period of light-variation, which is 17.12 days. While this star has already been announced[1] by the discoverer, it is included here for completeness.

J. H. Moore.

March 7, 1906.

SPECTROGRAPHIC OBSERVATIONS

FOUR STARS WITH VARIABLE RADIAL VELOCITIES

B. D. $-1°.1004$ ($\alpha = 5^h\ 36^m$; $\delta = -1°\ 11'$; Mag. = 5.1)

Plate	Date	G. M. T.	No. Lines Measured	Velocity
I B 518	1905 February 13	$15^h\ 31^m$	5	+ 30 km
I B² 659	1906 January 26	15 56	8	+ 19
683	February 12	13 53	6	+132
688	February 16	12 55	6	− 34

The spectrum is of the *Orion* type, and the lines are broad, least so on Plate 688. The helium line λ 4388, although about the best measurable line, appears to have a distinctly different displacement from the other lines on most of the plates, and it is not used in deriving the velocities. There does not seem to be other evidence of the visible existence of a

[1] *Publications of the A. S. P.*, **18**, 66, 1906.

second component spectrum. The last two observations show that the period is short and the range large.

29 Canis Majoris ($\alpha = 7^h\ 14^m$; $\delta = -24°\ 23'$; Mag. $= 4.8$)

Plate	Date	G. M. T.	No. Lines Measured	Velocity
I B² 661...........	1906 January 26	$17^h\ 49^m$	2	−164 km
675...........	January 29	17 52	3	− 3
685...........	February 12	15 40	4	−243
690...........	February 16	14 56	4	− 92

The first and third plates were under-exposed, and the results are uncertain by many kilometers, but the displacements are remarkably large. The period is evidently short. The determinations of velocity depend chiefly upon $H\gamma$ and He λ4472; but on the last two plates $H\beta$ and λ4542 were also used.

In Harvard *Circulars* Nos. 16, 17, and 32, Professor E. C. Pickering called attention to the presence in this spectrum of the lines characteristic of ζ *Puppis*. It is made by Miss Cannon[1] the typical star of Class Oe, also showing a number of lines in addition to those seen in ζ *Puppis*.

Although I have had this star on the observing program of the Bruce spectrograph for several years, it was not until this season that time could be found for obtaining its spectrogram. The lines are so broad and diffuse on the four plates I have secured that an accurate determination of the wave-lengths of the lines of the ζ *Puppis* series unfortunately will not be possible.[2]

In this connection I may mention that on two nights of this winter I have been able to get sufficiently exposed spectrograms of ζ *Puppis* itself, although its meridian altitude is less than 8°. Here, again, the lines are so broad with the slit-spectrograph as to preclude accurate measurements. There are, however, other stars, notably *10 Lacertae*, in the spectra of which the "additional hydrogen lines" appear much more sharp than in the prototype. We have obtained numerous plates of this star which will be utilized, as soon as time permits, for the accurate determination of the wave-lengths of such of these lines as are in the region of good focus on our plates. Our plates of λ *Cephei*, recently noted by Professor Pickering as exhibiting these lines, will not yield results of precision on account of the diffuseness of all the lines in the spectrum.

[1] Harvard *Annals*, **28**, 148–50.

[2] Note added to proofsheets. Spectrograms just obtained of the star *30* or τ *Canis Majoris* (24′ south of *29*), which has a somewhat similar spectrum, show that it also has a variable radial velocity of large range.

μ Orionis ($\alpha = 5^h\ 57^m$, $\delta = +9°\ 39'$, Mag. = 4.3)

Plate	Date	G. M. T.	No. Lines Measured	Velocity
II B 25	1905 November 24	$18^h\ 53^m$	13	+65 km
I B 624	December 9	18 6	6	+46
I B^2 650	December 25	16 32	7	+58
B^2 623	1906 January 5	16 55	16	+37.8
B^2 631	January 8	18 58	13	+71.5
I B^2 669	January 29	14 12	5	+21
B^2 641	February 9	15 0	18	+63.6

This spectrum is of type Ia2–Ia3, not differing much from that of *α Cygni*, and is well suited for measurement. The observations of January 5 and 8 indicate that the period is short. A rather high velocity of the system is suggested, though it is quite likely that smaller values of the radial velocity will be found on future plates than on those so far obtained.

Some of the plates give faint evidences of the lines of the spectrum of a second component. Thus three such faint lines were measured on plate $B^2$623, and gave accordant values, the mean of which was +104 km. I am not yet prepared, however, to vouch for the visible reality of the second component. The plates taken with one prism (I B), and two prisms (II B), are naturally less accurately measurable than those obtained with the full dispersion of three prisms (B).

T Monocerotis ($\alpha = 6^h\ 20^m$; $\delta = +7°\ 8'$; Mag. = 6–8)

Plate	Date	G. M. T.	No. Lines Measured	Velocity
I A 9	1905 November 3	$21^h\ 30^m$	11	+17 km
II B 26	November 24	21 40	14	+13
I B 643	December 15	20 30	14	+ 7

This variable star has a spectrum of the solar type, and can be well measured if high enough dispersion is employed. The star's faintness makes a long exposure necessary and prevents the accumulation of plates, particularly as the star is situated near many others of our observing programs which also require attention. The exposure times for the three plates above were 210, 224, and 140 minutes, respectively. The result for the first plate is least reliable; that for the second, the most so. The range of velocity so far observed is rather small, perhaps less than might be expected; but I believe it to be real. The star's period is 27.0 days, the maximum occurring 8 days after minimum. According to the current ephemeris, the first plate was taken 19 days after minimum, or 8 days

before maximum; the second plate at five days after maximum, and the third plate at one day before maximum. It seems hardly worth while, however, to draw any inferences from these relations until additional plates are available.

The plates so far referred to in this note were taken by the writer, with the assistance of Mr. Sullivan.

OBSERVATIONS OF α *DRACONIS*

This star I casually placed on the observing list for the latter part of the night of January 5. A glance at the plate next morning showed a large negative displacement (subsequently measured to be —50 km, unreduced to the Sun). Visual comparison of this plate with the only one obtained up to that time with the Bruce spectrograph, taken by Mr. Adams on November 20, 1901, which had a positive displacement, indicated that the star's velocity varies. I carelessly overlooked the previous announcement of this fact by Messrs. Campbell and Curtis[1] until several new plates had been obtained and measured.

Meanwhile appeared Mr. Moore's interesting note[2] on the Lick observations of this star, which by a remarkable coincidence yielded on five dates a practically identical result (—40 to —43 km), with a different value (0 km) on only one date, upon which the establishment of the binary character of the star depended. The communication of our results, therefore, would seem to be appropriate at this time. All the plates have been taken by Mr. Barrett, with the exception of the first, obtained by Mr. Adams.

Plate	Date	G. M. T.	No. Lines Measured	Velocity
B 245	1901 November 20	22^h 8^m	8	+20 km
B^2 627	1906 January 5	23 37	8	−42
B^2 633	January 8	21 56	1	−55
I B^2 664	January 26	21 17	5	− 9
I B^2 678	January 29	19 28	3	+ 1
B^2 644	February 9	22 20	7	+24

The first plate was measured in 1902 by Mr. Adams, who obtained from 6 lines a value agreeing within half a kilometer with my recent measure given above.

The value for January 8 depends upon the excellent *Mg* line λ4481. The above observations appear to be satisfied by a period of between 51 and 52 days, which apparently also fits the Lick observations.

[1] *Astrophysical Journal*, **18**, 307, 1903.

[2] *Publications of the A. S. P.*, **18**, 66, 1906.

The spectrum is assigned by Vogel and Wilsing to type Ia2, and by Miss Maury to group VII*a*. The helium lines of the *Orion* type are faintly visible on some of the plates, and I was able to measure λ 4472 on one plate, while on one of the one-prism plates I measured the silicon lines at λ 4128 and 4131. Some of the enhanced lines of *Ti* and *Fe* are quite well measurable. The star should strictly be assigned to the *Orion* type, a remark which would apply to some other stars ordinarily classified under Ia2. (For instance Miss Maury[1] notes a trace of λ 4472 in the spectrum of *a Lyrae*, which appears to be confirmed by our plates.)

SPECTRUM OF *PLEIONE*

In recently photographing the spectrum of *Pleione*, I have been surprised by the faintness or absence of the bright hydrogen lines, which were fairly conspicuous on spectrograms obtained elsewhere a few years ago. Their presence (superposed upon the broader dark lines) was first announced by Professor E. C. Pickering,[2] as a result of an examination of the Harvard plates by Miss Maury.

I recall taking several spectrograms of the star at Potsdam in 1891 or 1892, which plainly showed the emission lines. Our plates were taken on the following dates: 1905, November 10, December 4, December 25; 1906, January 26, January 29, February 19.

Professor Pickering has kindly informed me in regard to the plates taken with the objective-prism. Bright $H\beta$ was well shown on negatives taken December 28, 1888, and December 31, 1896. An examination of twenty-two plates taken on thirteen nights in the autumn of 1896 has been made by Miss Cannon, and she is unable to detect any certain changes in the intensity of bright $H\beta$ on these plates.

I am permitted to quote from a letter dated February 20, 1906, in which Professor Pickering says: "The line $H\beta$ does not now appear bright on our photographs of *Pleione*." It does not appear on a print of the *Pleiades* from a negative taken January 30, 1906, with the same apparatus as the early photographs, which illustrates Harvard *Circular* No. 110. (See p. 256 of this issue.) It would be interesting to know what testimony may be given by plates taken at other observatories in regard to variability of the intensity of the bright lines of *Pleione*.

The equipment of the Bruce spectrograph has recently been much improved by the addition of a triple uncemented camera lens, designated above as B[2], which was designed by Professor Hastings and constructed by Brashear. Its aperture is 57 mm and its focal length is 608 mm.

[1] Harvard *Annals*, **28**, 23.

[2] *Astronomische Nachrichten*, **123**, 95, 1889.

It has now been in use for nearly three months, and has been entirely free from the capricious changes in definition which have caused us great annoyance with our previous cemented triplets. It has not been found necessary to increase our exposure times appreciably as compared with those given with the cemented camera lenses.

EDWIN B. FROST.

YERKES OBSERVATORY,
March 14, 1906.

NOTE ON THE D. O. MILLS EXPEDITION TO THE SOUTHERN HEMISPHERE.

The two-year period of actual observation originally planned for the D. O. Mills Expedition to Santiago, Chile, terminated in October 1905, the installation of the observatory having been completed in October 1903. As has already been announced in *Publications of the Astronomical Society of the Pacific*, Mr. Mills has most generously offered to continue the work of the expedition for five additional years. Acting Astronomer Heber D. Curtis, accompanied by his family, sailed from San Francisco on December 30, 1905, via Panama, to Chile, to take charge of the observatory for this new period of work. He expected to reach his destination about February 15. Immediately following Dr. Curtis' arrival, Acting Astronomer W. H. Wright and Mrs. Wright will return to Mount Hamilton. As Dr. Curtis' duties in connection with the Crocker Eclipse Expedition to Labrador prevented him from leaving earlier for Chile, Professor Wright has kindly extended the term of his residence there, awaiting the arrival of his successor.

Dr. H. K. Palmer, assistant in the D. O. Mills Observatory, returned to Mount Hamilton in December 1905, after an absence of nearly three years. He is engaged at present in measuring and reducing the spectrograms secured in Chile. His successor will soon leave for Santiago. Mr. Mills has at the same time provided for extensive improvements in and additions to the equipment of the observatory, several of which are nearing completion. The 30-foot Warner and Swasey dome of steel frame, formerly covered with heavy painted canvas, has been re-covered with metal. A ball thrust-bearing and two roller side-bearings have been provided for the declination axis of the telescope. Two-prism and one-prism spectrographs have been built, in order that radial velocity determinations may be carried to fainter stars. Professor Wright's experience has made it practically certain that rapid changes in focal length and other sources of disturbance in the stellar images are due to rapid changes

of the temperature of the mirror during the first hours of the night. The question of maintaining artificially the temperature of large mirrors during the daytime at the reading estimated for the atmosphere for the evening that follows has often been discussed in past years by the members of our staff and by others. During my absence in Europe last summer and fall Dr. Curtis worked out the details for such a refrigerating scheme, and the apparatus has been shipped for installation and trial on Cerro San Cristobal. Apparatus for quick re-silvering of the 37-inch mirror is under construction. Another building will be erected on the summit of the mountain to accommodate a machine shop, equipped with lathe and small tools, and to contain rooms for the observers. An electric power line will be installed to convey current from the city for the machine shop, refrigerator, and comparison arc, in addition to minor uses. Telephone connections between the observatory on the summit and the astronomer's residence in the city, and many other lesser conveniences and improvements will be made.

W. W. CAMPBELL.

FEBRUARY 25, 1906.

SAMUEL PIERPONT LANGLEY

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SAMUEL PIERPONT LANGLEY

By C. G. ABBOT

Samuel Pierpont Langley achieved distinction as one of the earliest and foremost of the students of astrophysics, but in his later life added to his great and world-wide reputation by a service of over eighteen years as secretary of the Smithsonian Institution, during which he conducted his remarkable experiments in aërial navigation, and founded and directed the Smithsonian Astrophysical Observatory. Born in Roxbury, Mass., August 22, 1834, he was graduated from the Boston High School in 1851, and took up the study of civil engineering and architecture, which professions he subsequently practiced until he had laid by what was for those times a fair competency. During the years 1864 and 1865 he traveled extensively in Europe, and visited the principal observatories and learned societies there. During this time he formed the purpose of devoting the remainder of his life to scientific pursuits, and primarily to astronomical investigations, for he had been from childhood eagerly interested in astronomy. Returning from Europe, he was appointed assistant at the Harvard College Observatory in 1865, and assistant professor of mathematics in the United States Naval Academy in 1866. While at Annapolis he reorganized the small observatory there. In the same year he became director of the Allegheny Observatory, and professor of astronomy and physics in the Western University of Pennsylvania, where he remained

twenty years. In 1887 he was appointed first assistant secretary of the Smithsonian Institution, and later in the same year, after the death of Secretary Baird, he was elected secretary of the Smithsonian Institution, which high position he retained until his death, February 27, 1906.

As secretary, he brought the Smithsonian Institution more prominently before the notice of the foreign public than had either of his predecessors. This was due in part to his great personal reputation as an astronomer, fully established abroad before his accession to the secretaryship; to his far-famed experiments on aërial flight made during his incumbency; to his frequent journeys abroad in the interests of the Institution; to his careful attention to the systems of publication and international exchanges of scientific publications and specimens; and to his broad administration of great bequests, like the Hodgkins Fund for the promotion of investigations concerning the atmospheric air. During his administration the funds controlled by the Institution were largely increased. He will be remembered as the founder of the Smithsonian Astrophysical Observatory and of the National Zoölogical Park. His interests were extremely broad, including, besides the lines of scientific work in which he became renowned, the love of art, of literature, of antiquities, and especially of the young. One of his later official acts was to provide a room of the Institution, beautifully lighted and decorated, including the choicest of remarkable specimens from the collections of the Institution and National Museum, labeled interestingly in plain English, for arousing the interest and delight of children; and this he called "The Children's Room."

Mr. Langley felt that he was risking a well-earned and valued reputation, when he undertook his researches in aërial navigation. The subject had long been principally given over to cranks, and was more likely to bring ridicule than reward to any serious investigator who might study it. But the flight of the soaring birds had been an enticing mystery to him from the days when, as a boy, he lay upon his back and watched their beautiful evolutions and wondered how they could accomplish them; and Mr. Langley determined to use his skill, his influence, and his reputation in an attempt to solve the mystery of soaring flight. His two papers,

"Experiments in Aërodynamics" (1891) and "The Internal Work of the Wind" (1893), created a profound impression, and have done very much to put the problem of flight on a sound experimental basis. Basing his work on the foundation he had thus laid, Mr. Langley succeeded in 1896 in designing and flying a large model of a machine which he called an "aërodrome," heavier than the air, and sustained like a bird by wings. But as he was several years in advance of the present wide application of the gasoline motor, his success then was only possible after he had, with infinite perseverance, obtained a steam engine weighing but five pounds to the horse-power. From this time to 1903, successful flights of large aërodrome models were repeatedly made under his direction, and, at the request of the Bureau of Ordnance and Fortification of the War Department, he superintended the construction, under the immediate charge of Mr. C. M. Manly, of an aërodrome designed to carry a man, and driven by a powerful gasoline motor. In two trials of this machine made on the Potomac River in the autumn and winter of 1903, the experiments were foiled in each instance by accidents during the act of launching, so that the capacity of the device for free flight was never put to test. Fortunately no loss of life occurred in these trials, and the machine was in neither case permanently injured, but a combination of untoward circumstances, including failing health, dissuaded Mr. Langley from continuing the experiments, though it was the firm belief of those best able to judge that success was within reach.

As an astronomer Mr. Langley was from the first interested chiefly in the most original of investigations relating to the physical nature and functions of the celestial bodies, rather than in measurements of time, distance, and position. But during the whole period when he was director of the Allegheny Observatory the funds available to him for research scarcely amounted to $5,000 a year, and were chiefly gained by his own efforts in enlisting the co-operation of friends, and by another measure which shows his genius for adapting means to an end. Among the first steps which he took as director was to offer to supply from the Allegheny Observatory accurate time to all the lines under the control of the Pennsylvania Railroad. This offer was accepted, and marks the first considerable trial in

this country of the now universal practice of furnishing uniform time-service to railroads. The compensation for this service was one of the chief sources of support to Mr. Langley's work during the whole time that he was at Allegheny.

As an observer at the eye-end of an equatorial it is doubtful if there was ever Mr. Langley's superior. His visual studies of the minute structure of the Sun's surface have long been classical. His capacity for seeing and delineating what he saw was so full and exact that his sun-spot drawings made at Allegheny prior to 1875 are even yet regarded as the best recorded evidence of the structure of sun-spots. The present writer has indeed been repeatedly assured by Professor G. E. Hale, who has enjoyed the choicest opportunities for examining the Sun, both with the 40-inch refractor of the Yerkes Observatory and with the horizontal telescope on Mount Wilson, and also during various expeditions to high mountain peaks, that in the best views of sun-spots he has ever had, the better they were seen, the more nearly have they appeared as shown in Langley's drawings.

Mr. Langley observed the total solar eclipses of 1869, 1870, 1878, and 1900, and his account of his observations of 1878 from the summit of Pike's Peak is particularly notable. His visual observations of the solar spectrum, made before the days of Rowland's great contribution to spectroscopy, are even yet favorably referred to, notwithstanding the immense advantages which present day observers have in the Rowland gratings, and the use of photography.

But Mr. Langley's distinction as a visual observer pales before his great contributions to the study of radiation by electrical thermometry. As early as 1870 he began to study the radiation of the Sun by heat methods. He made careful investigations of the relative intensity of radiation from different parts of the Sun's disk, including sun-spots. In these studies he employed the thermopile, but he became more and more dissatisfied with this instrument, on account of its slowness of response and the inadequacy of its sensitiveness to the measurements which he desired to make. His experiments with this instrument on the solar spectrum convinced him that something as much superior to the thermopile of those

days as that was to the thermometer would be required before any satisfactory progress in this direction would be possible. From 1878 to 1880 he was engaged in various attempts to devise a more perfect instrument for measuring radiation, and succeeded at length in the invention of the bolometer, an instrument now in world-wide use. With this new instrument, essentially an electrical thermometer on the principle of Wheatstone's bridge, he proceeded at once to explore the spectrum of the Sun; extended it and mapped it in regions before almost unsuspected, beyond the red; studied the action of the Earth's atmosphere in selectively scattering and absorbing the solar rays of all wave-lengths; estimated the solar constant of radiation by a new method, making for this purpose an expedition to a high mountain 3,000 miles distant from Allegheny; determined the connection between temperature and distribution of radiation in the spectrum of heated terrestrial substances; and studied the spectrum and estimated the temperature of the Moon. All these epoch-making investigations he directed, published, and largely performed with his own hands, in the years between 1880 and 1888.

Mr. Langley's investigations in radiation fall readily into several distinct groups as follows:

(1) The distribution of radiation over the surface of the Sun, and in sun-spots.

He began these studies about 1870, and published repeatedly on the subject until 1877, giving the results of measures with the thermopile on different parts of a large solar image. The rate of diminution of brightness from the center to the edge of the Sun was determined, along both polar and equatorial diameters, with the result that if any difference in these two directions existed, it was inappreciably small. At 98 per cent. of the radius from the center of the Sun's disk the radiation was found to have fallen off one-half, and it was noted with surprise that the umbra of a sun-spot appeared to emit more radiation than the still brilliant edge of the Sun's disk. A determination was made of the direct effect of sun-spots to diminish the total radiation of the Sun, and this, it was found, could rarely reach one-tenth of 1 per cent. Mr. Langley inferred from his experiments on the absorption of solar

radiation in the Sun's envelope that very great changes of the temperature of the Earth would be likely to result from reasonably conceivable variations in solar absorption; but these inferences, based on Newton's law of cooling, would now be subject to revision in the light of the present acceptation of Stefan's law of radiation. It is characteristic of Mr. Langley's caution, however, that he himself called attention to the uncertainty of these estimates and the hesitation with which he made them.

In 1901 the study of the distribution of radiation over the Sun's disk and in sun-spots was again taken up under Mr. Langley's direction at the Smithsonian Astrophysical Observatory, and since then by the aid of the sensitive automatic recording bolometer, not only the distribution of the total radiation, but that of many different parts of the spectrum between $0.4\,\mu$ and $2.5\,\mu$, has been determined on very numerous occasions both on the general photosphere and in spots. This work is not as yet fully published, but brief notices of it may be found in the *Reports* of the Smithsonian Institution.

(2) The solar energy-spectrum and its extension toward the infra-red.

Mr. Langley's primary object in devising the bolometer was to obtain an instrument for the study of the distribution of radiation in the solar spectrum, and in 1880, even before he had chosen the name "bolometer" for the new instrument, he employed it to determine for the first time the intensity of energy in the solar spectrum formed by a diffraction grating. He continued bolometric determinations of the prismatic solar energy-spectrum at Allegheny for several years, and was the first to obtain for infra-red work large, optically-good prisms of rock-salt. While on Mount Whitney in 1881 he discovered evidences of solar radiation extending beyond all previously known wave-lengths as far as $5\,\mu$ in the infra-red. After the foundation of the Smithsonian Astrophysical Observatory, and his introduction of automatic photographic recording devices for the bolometer, the infra-red solar spectrum was carefully explored under Mr. Langley's direction to fix the place of its absorption lines and bands, from $0.76\,\mu$ to $5.3\,\mu$. This work formed the principal matter of Volume I of the *Annals of the Astrophysical*

Observatory of the Smithsonian Institution. Still more recently the exact distribution of intensities in the solar spectrum from 0.37 μ to 2.5 μ has been studied at the Astrophysical Observatory under his direction, and brief mention of these results, as yet not fully published, may be found in the *Smithsonian Reports.*

(3) The lunar energy-spectrum and the probable temperature of the Moon.

Researches of the most extreme difficulty were carried on by Mr. Langley and Mr. Very from 1883 to 1888, at Allegheny, to determine the probable temperature of the Moon. These involved the study of the Moon's spectrum by the bolometer—a task which I venture to think few have the hardihood to repeat even now. For the temperature of the Moon is so low that its own proper spectrum differs little from that of the walls of the room, and all the other terrestrial surroundings, and its rays suffer the most variable and perplexing absorption from all the vapors of our atmosphere, including not only water and carbonic acid, but all the products of combustion of coal which pollute more and more the atmosphere over our cities. Mr. Langley has told the writer that none of his other researches cost him so much trouble with so little measure of satisfaction as this on the lunar temperature. He concluded finally that the Moon's temperature is a little above 0° Centigrade, but Mr. Very has more recently again worked over the material and has reached a result somewhat higher.

(4) Spectra of terrestrial sources, and the determination of hitherto unmeasured wave-lengths.

During the lunar research the energy-spectra of blackened metals at various temperatures were studied by Mr. Langley, but he did not proceed so far with this investigation as to derive experimentally the laws connecting radiation and temperature, though he wished very much to find time to do so. By combining two spectroscopes, one containing a Rowland grating and the other a rock-salt prism, he determined the dispersion of rock-salt as far as 5.3 μ in 1885. This dispersion-curve was again determined by his method, and under his direction, at the Smithsonian Observatory in 1898. A most interesting terrestrial source of radiation which he examined was the Cuban fire-fly, *Pyrophorus noctilucus,* whose light he com-

pared with that of the electric arc and other ordinary sources of illumination, and proved the immense relative economy of nature's source of light.

(5) The absorption of the Earth's atmosphere on the radiation of the Sun, and the determination of the solar constant of radiation.

Hardly had Mr. Langley fixed with fair precision the general form of the solar energy-spectrum, when he proceeded to determine the influence of the Earth's atmosphere to diminish solar radiation at the surface of the Earth. He readily observed that the air exerts both a general and a selective action in diminishing solar radiation; and that, while the former increases steadily from the extreme infra-red to beyond the visible limit of the violet, the latter comprises great bands of increasing intensity as we go farther and farther in the infra-red; so that at length the absorption is found to be total for very considerable gaps in the infra-red solar spectrum. The consideration of these differences in apparent atmospheric absorption led him to the weighty conclusion that the total effect of the atmosphere to diminish the solar radiation could not possibly be estimated without studying all parts of the spectrum separately in detail, and that all previous estimates of atmospheric absorption, based on actinometric or photometric measurements of the total radiation were necessarily too low. He was so profoundly convinced of the great practical utility and crying need of exact measurements, which could be used to determine the total amount of solar radiation as it reaches the outer limits of our atmosphere, that, after making preliminary measurements at Allegheny, he enlisted the aid of wealthy friends, and of the general government, to send out in 1881, and publish the results of, a solar-constant expedition under his direction to Mount Whitney in California.

The report of the Mount Whitney Expedition is a monument to the energy, perseverance, originality, and skill in observation of Mr. Langley, and reflects great credit also upon the wonderful experimental ability of the late Professor Keeler, whose assistance on the Mount Whitney expedition Mr. Langley ever spoke of in terms of the highest praise and gratitude. The difficulties overcome by Langley and Keeler in using the bolometer at Lone Pine and on Mount Whitney cannot in our day be adequately realized;

and it is wonderful with what a degree of substantial accuracy they were able, in those extraordinarily difficult conditions, to determine the form of the solar energy-spectrum, and the effect upon it of terrestrial absorption.

Soon after coming to the Smithsonian Institution, Mr. Langley, by his personal efforts and influence, founded the Smithsonian Astrophysical Observatory. His aim from its inception was to direct its studies in lines calculated to be of practical utility to mankind, by increasing knowledge of the natural agencies which control climate and life. Quoting from the introduction of the Mount Whitney report, he believed that

> If the observation of the amount of heat the Sun sends the Earth is among the most important and difficult in astronomical physics, it may be termed the fundamental problem of meteorology, nearly all whose phenomena would become predictable, if we knew both the original quantity and kind of this heat; how it affects the constituents of the atmosphere on its passage earthward; how much of it reaches the soil; how, through the aid of the atmosphere, it maintains the surface temperature of this planet; and how, in diminished quantity and altered kind, it is finally returned to outer space.

In his prior work with the bolometer he had never diverted time from use of it to perfect the instrument, but at the Astrophysical Observatory he introduced in 1892 a continuous automatic photographic registering device to record its indications. Thus it became possible to map in a few minutes the whole energy-spectrum of the Sun in a manner adapted to bring out details of it hitherto impossible to detect with years of work. With this powerful instrument the infra-red energy-spectrum of the Sun was carefully mapped from wave-length $0.76\,\mu$ to wave-length $5.3\,\mu$, revealing about 700 absorption lines and bands in this invisible region. This, with subsidiary investigations, formed the matter of the first volume of the *Annals* of the Astrophysical Observatory, published in 1900. At the conclusion of this work the activities of the observatory were directed toward the solution of that fundamental question: Is the emission of radiation by the Sun substantially constant in amount, or does it vary sufficiently to produce marked and predictable effects on the climate of the Earth? This investigation had not at the time of Mr. Langley's death been completed, but it had proceeded so far as to indicate a very strong probability that the solar radiation

outside the Earth's atmosphere varies notably and frequently, in a manner adapted to profoundly influence the temperature of the Earth.

The inventiveness of mind displayed by Mr. Langley in all his work is remarkable. Among many devices which he originated are means for determining times of transit without personal equation; means for observing sudden phenomena, by substituting the observation of a place for a time; the bolometer and its automatic registering devices, already mentioned; means for producing perfect seeing, by stirring the column of air traversed by the beam. He also reinvented, without knowledge of its earlier use, the principle of the cœlostat, and employed that instrument about 1880 at Allegheny.

Mr. Langley's published astronomical work is very extensive. The most important titles are as follows:

Minute Structure of the Solar Photosphere. *Am. Jour. Sci.*, **7**, 87–101, February 1874.

Comparison of Certain Theories of Solar Structure with Observation. *Am. Jour. Sci.*, **9**, 192–198, March 1875.

Sur la température relative des diverses régions du Soleil. Étude des radiations superficielles du Soleil. *Comptes Rendus*, **80**, 746–749, 819–822, 1875; **81**, 436–439, 1875.

Measurement of the Direct Effect of Sun-Spots on Terrestrial Climates. *Monthly Notices Royal Astronomical Society*, **37**, 5–11, November 1876.

Certain Remarkable Groups in the Lower Spectrum. *Proc. Am. Academy*, **14**, 92–105, 1878.

The Bolometer and Radiant Energy. *Proc. Am. Acad.*, **16**, 342–358, 1881.

The Selective Absorption of Solar Energy. *Am. Jour. Sci.*, **25**, 169–196, March 1883.

Experimental Determination of Wave-lengths in the Invisible Prismatic Spectrum. *Am. Jour. Sci.*, **27**, 169–188, March 1884.

The Amount of the Atmospheric Absorption. *Am. Jour. Sci.*, **28**, 163–180, September 1884.

Researches on the Solar Heat and its Absorption by the Earth's Atmosphere. A Report of the Mount Whitney Expedition. *Professional Papers, Signal Service*, No. XV, 1884.

The New Astronomy. *Century Magazine*, 1884–5.

On the Temperature of the Surface of the Moon. *Memoirs Nat. Acad. Sci.*, **3**, 1884.

Observations of Invisible Heat Spectra and the Recognition of Hitherto Unmeasured Wave-lengths. *Proc. Am. Assn.*, **34**, 1885, and *Am. Jour. Sci.*, **31**, 1–12, January 1886.

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The Temperature of the Moon. *Memoirs Nat. Acad. Sci.*, **4**, 107–212, 1887.

Energy and Vision. *Am. Jour. Sci.*, **36**, 359–379, November 1888.

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Good Seeing. *Am. Jour. Sci.*, **15**, 89–91, February 1903.

The Solar Constant and Related Problems. *Astrophysical Journal*, **17**, 89–99, March 1903.

The 1900 Solar Eclipse Expedition of the Astrophysical Observatory of the Smithsonian Institution, 1904.

Mr. Langley was repeatedly honored by domestic and foreign scientific societies and institutions of learning. He was a correspondent of the Institute of France; a foreign member of the Royal Society of London, of the Royal Society of Edinburgh, and of the Accademia dei Lincei, of Rome; a member of the National Academy of Sciences, and many other American and foreign scientific societies. He received the degree of D.C.L. from Oxford, D.Sc. from Cambridge, and among numerous others the degree of LL.D. from the Universities of Harvard, Princeton, Michigan, and Wisconsin. He was awarded the Janssen medal of the Institute of France, the Rumford medal of the Royal Society of London, and of the American Academy of Arts and Sciences; the Henry Draper medal of the National Academy of Sciences, and others.

Mr. Langley's habit of mind led him to experimental work rather than to mathematical analysis. He was, nevertheless, an acute reasoner, and an excellent example of this is found in his proof of the necessity of dealing with homogenous rays in determining the solar constant of radiation. His attitude was rather that of the eager searcher for a reason for some phenomena that had excited his interest, than that of one who sees a gap in the advance of science, and feels that some good work ought to be put in there. Whether from natural disposition, or from deliberate conviction that time could be saved thereby, or both, his method of attack upon a new experimental problem was to make rough trials at once, to improve the method as experience dictated, and at length reach the final dispositions as the result of correcting this and that detail

after trial, rather than by first spending long and careful study over every detail before reducing any part of the work to practice. Whatever may be our views of the comparative merits of the two methods, there can be no question of his conspicuous success, and of the enormous amount and excellent character of his experimental work. A very valuable rule with him was to write down at the beginning of each day the object to be kept in view that day, to make clear notes of all observations and proposals, and to keep in the notebook itself all those scraps of writing or computing which are so often jotted on slips of paper and lost.

It has fallen to the writer to repeat many of the pioneer experiments made by Mr. Langley, employing apparatus which, through Mr. Langley's efforts and encouragement, had become a thousand times better adapted to the work than that which was at his disposal to make the original measurements. The instruments he had to work with from 1870 to 1888 were indeed so totally inadequate to the difficult measurements which his active pioneer instinct of investigation required of them, that it is little short of a miracle that he was able, even with the aid of the assistants of uncommon ability whom, with his keen discrimination of men, he employed, to obtain results even approximating the truth. But I have been again and again surprised and delighted to find that the experimental results which he published a quarter of a century ago represent almost exactly the mean of mine, and, so far as I am now aware, there is no single one of the pioneer observations on which Mr. Langley's reputation rests, which the improved devices of the present do not substantially confirm.

In his published papers, his lectures, and in all his correspondence, Mr. Langley exhibits a grace and clearness of style, and an accuracy in the choice of words, equaled by few professional writers. He could hardly satisfy his own demands in these particulars, however, for he was continually altering and improving the style in draft after draft, and even in printer's proofs. It was a primary object with him to present every subject he published so clearly and fully that each article would be complete in itself, and adapted to be read with interest by educated persons not specialists in the subject.

The secret of the success of this great man is easily found; for he combined with an eagerness to push on in scientific pursuits which amounted at times to impatience, a perseverance which no obstacles or failures could daunt; with great originality and inventiveness of mind, a breadth of view which appreciated the best in human life and thought; with ambition for success and distinction in his own work, the altruism which led him to direct that work to improve the condition of all mankind.

ON THE DISTRIBUTION OF BRIGHTNESS OF THE ULTRA-VIOLET LIGHT ON THE SUN'S DISK [1]

By K. SCHWARZSCHILD and W. VILLIGER

I

The decrease of brightness from the center toward the edge on the Sun's disk has frequently been a subject of investigation. From recent decades three precise series of measurements are available. In 1871 H. C. Vogel,[2] by making exposures on silver chloride paper, determined the decrease of brightness for all of the photographically active rays; in 1877[3] he observed visually with the spectral photometer a series of wave-lengths in the visible spectrum. Very[4] later investigated the distribution of brightness throughout the visible spectrum and on into the infra-red to $\lambda\ 1.5\ \mu$, with the bolometer.

The present investigation extends the range of wave-lengths toward the ultra-violet as far as $\lambda\ 0.32$. The method employed was the following: In Schott's Glass Works at Jena kinds of glass known as "ultra-violet glass" have been manufactured for some time, which show, in layers of several centimeters thickness, good transparency for the ultra-violet light from $\lambda\ 0.30$ downward. On the other side, it is known that thin layers of silver, which are entirely opaque to the longer wave-lengths and which are the best mirrors, lose their power of reflection quite suddenly in the region of about $0.34\ \mu$, and become transparent. Professor R. Straubel conceived the idea of making a light-filter for ultra-violet light by covering such ultra-violet glass with a thin film of silver.

For just such solar photographs as we had in mind, this idea furnished an exceedingly simple procedure, in that nothing further was necessary than to silver the objective of ultra-violet glass, used in the observation, on one or more surfaces, in our case two. In order to be certain which wave-lengths were transmitted by the light-filter

[1] A preliminary communication, based upon a smaller number of plates, appeared in the *Physikalische Zeitschrift*, **6**, 737–744, 1905.

[2] *Sitzungsberichte der Berliner Akademie*, 1871.

[3] *Ibid.*, 1877.

[4] *Astrophysical Journal*, **16**, 73–91, 1902.

thus produced, Dr. Henker very kindly made several exposures to the iron spectrum with the help of this silvered objective. The result was that only a narrow strip of the spectrum, from wave-length 0.320 to 0.325 μ, was transmitted; and even with a decided over-exposure this only extended from 0.315 to 0.327 μ.

The objective was of 120 mm clear aperture, of 325 cm focus, and was attached with its tube to the refractor of the experimental observatory of the Zeiss Works at Jena. In front of the plate an instantaneous shutter was fastened. With an exposure of about $\frac{1}{50}$ second, very sharp, normally exposed pictures of the Sun were obtained.

The photometric principle consisted in the use of sector diaphragms before the objective, which principle is entirely free from objection in measurements of surface brightness. The light was diaphragmed down to $\frac{1}{2}$ and $\frac{1}{4}$ by three sector openings each of either 60° or 30° angle.

The first photographs were taken two years ago, but there was a series of minor obstacles to be overcome before usable results could be obtained. At first three and four surfaces of the objective were silvered, making a long exposure time necessary which was unfavorable for the sharpness of the image of the Sun. Further, it appeared that the speed of the shutter changed during its passage over the plate. Hence only those measures could be employed which were referred to a diameter of the Sun perpendicular to the motion of the shutter. The speed of the shutter from one exposure to another seems to be sufficiently constant, as is shown in the results below. In order to avoid the effects of absorption of the Earth's atmosphere as much as possible, the observations were taken close to the meridian, the motion of the shutter was vertical, and it was upon the horizontal diameter of the Sun along which the distribution of brightness was measured.

On each plate, of size 9×12 cm, three exposures were made, with full aperture, and with the diaphragms $\frac{1}{2}$ and $\frac{1}{4}$.

In order further to weaken the effect of the different transparency of the silver film, or of the glass in different parts of the objective, the exposures were always repeated in three different positions cf the sector diaphragm. The sequence of the images on the plate was also changed, so that the picture exposed with full aperture was sometimes

in the center and sometimes on the edge of the plate, since for a little while we had a suspicion that the parts around the edge of the plate were a little more strongly blackened with the same illumination. This precaution was observed later, although the suspicion was not confirmed in general.

A series of observations therefore finally consisted of six plates with three exposures each, in which the position of the diaphragms and the sequence of the pictures were changed in the manner indicated below.

The plates were measured at the Observatory at Göttingen with the Hartmann micro-photometer, with which the blackening of each part of the plate is compared with the blackening of a photographic wedge, and is numerically indicated in millimeters registering the amount of motion of the wedge. A measuring apparatus by Spindler and Hoyer was placed under the micro-photometer. This apparatus made it possible to read with certainty to $\frac{1}{100}$ mm the co-ordinates of the places photometrically measured. The measured spot itself had a diameter of 0.15 mm in the direction of the solar diameter under investigation; perpendicular to that, a diameter of 0.25 mm. It is possible to measure the blackening of a spot which is 0.07 mm distant from the edge, which for the size of the solar image is 0.005 of the radius, although on account of the rapid decrease of light toward the edge only a normal amount of accuracy can be obtained up to a distance of 0.15 mm from the edge.

Settings were first made under the measuring machine on the north and south edges of the Sun (the short side of the plate indicated the north and south directions with sufficient accuracy). The mean of the two readings gave the one co-ordinate of the solar diameter to be followed. Settings were then made on the east and west limbs of the Sun. The mean of these two settings gave the center of the Sun's image, and starting from this central position, settings were carried out at the distances given in the following table from east to west. The measurements were made by Herr E. Jastram.

After a great part of the measurements was completed, a source of error was noticed which occurs with Hartmann's micro-photometer if photometric measurements are made upon a very opaque portion of a plate in the immediate neighborhood of a larger area which is

very slightly opaque. The very bright light which then passes through the unblackened area is in part reflected at the objective of the observing microscope, and illuminates from in front the dark portion of the plate, so that it appears too bright. In the case of our measurements a very disturbing effect of this error could be noticed near the Sun's limb. It falsified the intensity deduced from the observations by 5 per cent. if the objective was clean, and by from 30 to 50 per cent. if dust had settled upon the objective so that it diffusely reflected still more light. The effect of the error was overcome by always covering the whole plate during the measurement by a black disk laid upon the plate and containing a small circular aperture only slightly larger than the spot to be measured. After the detection of this error, all the measures were repeated with the use of such a disk.

The following table gives the results of the new measurements for the five series of plates obtained last year. The second half of the last series had to be rejected, since the plates had received stray light. Subsequently plate No. 90 was also rejected, since the image obtained with the diaphragm $\frac{1}{2}$ differed too little from the image with the diaphragm $\frac{1}{4}$, and obviously the result was not the mean between the images with diaphragms 1 and $\frac{1}{4}$. In the following table ρ denotes the distance in millimeters from the center of the Sun's disk. The numbers following indicate the settings of the photometer wedge in millimeters. They are the means of two settings, one immediately following the other. It did not seem necessary to give both of the single settings, as they agreed always within a few tenths of a millimeter. Large readings in millimeters signify stronger degrees of blackening. The measured diameter of the image in millimeters is given below the photometer settings of every image.

TABLE I

SERIES I, MAY 28, 1905

ρ	Plate 66. Position I of Diaphragm						Plate 67. Position II of Diaphragm						Plate 68. Position III of Diaphragm					
	¼		½		1		¼		½		1		¼		½		1	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	52.4		57.4		62.1		53.2		58.8		62.5		52.6		57.3		62.7	
4.0....	52.1	52.1	57.2	56.9	61.8	61.6	52.9	52.1	58.7	58.1	62.1	62.3	52.2	52.1	57.2	56.8	62.6	62.3
8.0....	51.7	50.6	56.1	55.5	61.1	60.8	51.6	51.5	57.7	57.6	61.6	61.2	51.5	51.1	56.9	55.9	61.6	61.6
11.0....	48.8	48.7	54.6	54.3	60.1	60.1	49.4	49.1	55.9	55.1	61.1	60.1	49.2	48.7	54.7	54.6	60.2	60.1
13.0....	46.9	44.6	52.8	51.1	57.7	57.3	47.3	47.3	54.1	52.9	59.2	58.2	46.9	46.8	52.9	52.3	57.9	58.1
14.0....	43.9	41.8	50.5	49.1	56.4	55.2	42.1	42.6	51.5	50.3	57.3	56.1	42.3	42.9	50.1	50.1	56.8	55.4
14.5....	41.4	39.4	47.7	46.5	54.6	54.6	38.9	38.9	49.1	48.6	55.6	54.2	39.9	39.1	48.2	47.5	54.7	54.9
14.7....	37.6	37.3	46.1	44.6	53.3	53.7	35.2	37.6	47.2	46.8	53.6	53.7	38.1	37.5	45.8	46.1	53.2	53.7
14.8....	37.1	31.5	45.9	42.3	52.4	52.2	30.5	35.1	46.3	43.6	53.1	53.1	36.5	33.8	45.6	43.6	52.4	52.8
14.9....	30.1	—	42.8	40.8	50.5	49.6	—	26.1	42.1	39.6	47.5	52.2	33.1	28.1	43.2	38.3	50.1	50.9
15.0....	—	—	29.5	27.6	46.1	45.1	—	—	—	21.1	44.1	47.1	—	—	—	—	42.5	42.3
Diameter..	29.96		29.98		30.01		29.83		29.93		30.00		29.94		29.90		30.06	

ρ	Plate 69. Position III of Diaphragm						Plate 70. Position II of Diaphragm						Plate 71. Position I of Diaphragm					
	½		1		¼		½		1		¼		½		1		¼	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	60.1		65.7		56.1		59.1		63.1		53.8		56.8		61.7		51.4	
4.0....	59.3	59.4	65.5	64.9	55.1	55.6	58.2	58.2	62.4	62.8	53.2	53.5	56.1	56.5	61.1	61.3	51.1	51.1
8.0....	58.9	58.9	64.3	64.1	53.8	54.2	57.7	57.6	61.7	62.5	52.6	52.3	55.4	55.7	60.2	61.1	50.3	50.4
11.0....	57.2	57.1	63.1	62.9	51.7	52.3	56.3	56.4	60.8	61.1	51.2	51.1	54.1	54.6	59.1	60.5	48.7	48.1
13.0....	55.6	55.5	61.4	61.5	49.1	49.9	53.8	54.6	58.6	59.6	47.9	48.1	51.2	52.8	57.3	58.3	44.9	45.2
14.0....	54.1	53.1	60.3	59.6	46.4	47.5	51.9	52.1	57.3	57.3	46.7	45.7	49.7	50.3	55.1	56.2	42.3	42.3
14.5....	51.4	50.8	59.1	57.8	44.9	45.1	50.1	50.4	55.2	55.9	43.6	42.6	47.1	48.5	53.6	54.6	40.6	39.1
14.7....	49.1	49.2	57.8	56.9	40.7	42.5	48.5	48.5	54.6	54.3	40.9	39.7	44.6	47.1	52.3	53.1	39.0	37.5
14.8....	48.1	47.6	56.8	54.6	39.4	40.8	47.3	47.3	53.7	53.6	40.6	38.1	44.1	44.3	51.6	51.4	35.1	34.7
14.9....	47.3	45.1	55.8	50.6	29.5	37.1	44.3	42.1	51.9	50.7	37.7	31.6	41.8	41.5	50.1	50.4	30.1	27.1
15.0....	41.1	32.1	47.2	43.4	—	23.5	37.6	23.8	42.9	43.1	—	—	28.9	32.1	42.9	42.3	—	—
Diameter..	29.90		29.90		29.90		29.95		29.95		29.97		29.95		29.96		29.96	

TABLE I—*Continued*

SERIES II, JUNE 27, 1905

ρ	Plate 75. Position I of Diaphragm						Plate 76. Position II of Diaphragm						Plate 77. Position III of Diaphragm					
	¼		½		1		¼		½		1		¼		½		1	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	52.6		56.9		61.5		50.8		56.1		60.6		52.6		56.9		60.9	
4.0....	52.4	52.3	56.5	56.3	61.2	61.1	50.1	50.1	55.5	55.6	59.0	59.1	52.5	52.1	56.4	56.2	60.7	60.6
8.0....	52.1	50.9	55.8	55.7	60.5	60.8	49.1	48.7	55.1	54.6	58.6	57.9	51.1	51.4	56.1	55.6	60.1	60.2
11.0....	49.7	50.1	54.6	54.3	58.9	60.1	47.7	47.9	53.2	53.2	58.1	56.8	49.7	49.6	55.6	54.6	58.1	59.1
13.0....	48.2	48.2	52.6	52.6	56.9	58.4	46.1	46.1	52.8	51.7	55.7	55.5	48.2	47.2	52.9	52.9	56.4	56.8
14.0....	46.4	46.1	50.7	50.1	54.7	56.2	43.7	44.1	49.5	49.2	54.1	53.2	45.5	46.3	50.8	50.3	54.7	55.6
14.5....	45.2	43.6	49.2	48.7	53.2	54.8	42.5	41.5	47.6	47.8	52.9	51.6	43.7	43.9	48.4	48.8	53.3	53.3
14.7....	42.3	42.2	47.5	47.9	51.4	54.2	41.3	40.7	46.5	46.4	51.7	50.7	41.9	42.6	47.6	47.3	51.6	52.7
14.8....	41.7	41.3	46.3	47.1	50.1	53.1	40.8	39.9	45.1	45.2	50.9	49.5	41.7	41.7	46.1	46.2	51.1	51.4
14.9....	39.6	39.5	46.1	45.1	47.8	51.1	38.1	37.9	43.1	41.2	47.1	45.8	38.1	40.2	43.1	43.4	47.6	46.5
Diameter..	29.75		29.85		29.85		29.77		29.80		29.82		29.85		29.80		29.85	

ρ	Plate 78. Position III of Diaphragm						Plate 79. Position II of Diaphragm						Plate 80. Position I of Diaphragm					
	½		1		¼		½		1		¼		½		1		¼	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	58.3		63.9		53.2		59.7		65.1		54.2		58.1		61.8		51.5	
4.0....	58.1	58.0	63.5	62.8	52.9	53.1	59.8	59.6	64.4	64.9	53.7	53.7	57.9	57.8	61.5	61.9	51 2	50.1
8.0....	57.5	56.5	62.6	62.1	52.2	52.4	58.5	58.5	63.8	63.7	53.2	53.1	57.5	56.6	61.2	60.8	50.1	49.5
11.0....	55.7	55.7	60.7	60.7	51.1	50.8	57.5	57.1	62.5	62.6	51.6	51.8	56.1	55.5	59.9	59.7	48.5	48.4
13.0....	53.2	53.8	59.5	59.1	48.6	48.5	54.8	55.3	60.7	60.8	49.5	49.6	53.2	54.2	57.2	57.2	46.2	46.7
14.0....	51.8	51.5	57.1	56.8	45.8	46.1	52.8	53.2	58.6	59.1	47.3	47.7	51.4	51.8	55.5	56.7	44.1	45.5
14.5....	50.1	49.7	55.7	54.7	44.6	44.6	51.6	50.8	56.8	56.8	45.4	45.4	49.6	49.2	53.2	53.3	42.6	42.8
14.7....	49.6	48.2	54.6	53.5	42.6	42.2	50.1	49.1	54.6	55.5	43.1	43.7	47.7	47.6	52.3	52.6	40.7	41.7
14.8....	47.1	47.2	53.5	52.5	40.9	40.4	48.1	47.7	54.1	54.7	41.9	42.5	47.5	46.4	51.2	51.3	40.2	41.1
14.9....	43.6	43.2	49.3	49.7	38.5	38.2	42.6	43.4	47.6	52.1	39.1	37.5	43.2	42.8	48.9	48.4	37.6	38.1
Diameter..	29.80		29.85		29.79		29.80		29.85		29.85		29.87		29.83		29.82	

TABLE I—*Continued*

SERIES III, JULY 26, 1905

ρ	Plate 87. Position I of Diaphragm						Plate 88. Position II of Diaphragm						Plate 89. Position III of Diaphragm					
	¼ East	¼ West	½ East	½ West	1 East	1 West	¼ East	¼ West	½ East	½ West	1 East	1 West	¼ East	¼ West	½ East	½ West	1 East	1 West
0.0....	52.1		59.6		65.3		51.8		58.8		64.4		50.5		56.1		60.7	
4.0....	51.9	51.7	58.9	59.2	64.6	64.5	51.5	51.5	58.2	57.9	64.1	63.8	50.1	49.9	55.8	55.6	60.1	60.1
8.0....	49.6	49.7	58.5	58.3	63.9	63.8	50.8	49.7	57.6	56.7	63.5	63.2	49.1	48.7	54.6	55.2	59.5	59.9
11.0....	48.1	47.8	56.3	56.6	63.2	62.7	48.2	46.7	55.9	55.1	62.6	61.2	46.4	46.2	53.5	53.2	57.8	58.8
13.0....	44.5	45.2	53.2	53.5	60.8	60.2	45.4	43.8	52.8	52.2	60.2	59.6	45.0	42.5	50.9	51.4	55.7	56.8
14.0....	40.6	40.7	51.1	50.9	58.7	58.4	40.9	39.6	50.6	49.1	57.6	58.1	40.7	39.2	48.2	48.2	54.1	55.4
14.5....	35.5	35.5	47.8	48.8	56.1	55.5	34.5	31.5	47.3	44.7	54.7	55.5	36.1	32.5	45.3	45.1	52.3	53.1
14.7....	32.3	33.6	44.7	45.1	55.5	54.1	—	—	44.3	42.3	53.5	53.7	—	22.6	42.2	42.4	50.1	52.4
14.8....	25.7	27.1	44.1	43.1	54.6	52.1	—	—	42.3	39.6	51.6	52.5	—	—	40.9	40.1	49.6	51.1
14.9....	—	—	39.6	38.5	50.5	47.1	—	—	39.1	37.1	48.4	49.7	—	—	36.2	35.5	45.1	48.1
Diameter..	29.85		29.90		29.93		29.85		29.86		29.90		30.00		29.90		29.95	

ρ	Plate 91. Position II of Diaphragm						Plate 92. Position I of Diaphragm					
	½ East	½ West	1 East	1 West	¼ East	¼ West	½ East	½ West	1 East	1 West	¼ East	¼ West
0.0....	60.0		65.3		53.0		59.1		65.8		53.7	
4.0....	59.4	59.6	64.8	65.1	52.7	52.6	58.6	58.2	65.4	65.1	53.6	52.3
8.0....	57.8	58.2	64.3	64.4	51.4	51.1	57.7	56.9	63.9	64.5	51.6	51.8
11.0....	56.2	57.1	63.2	63.4	49.5	48.7	56.3	55.4	63.3	62.8	49.3	49.1
13.0....	53.5	54.1	60.1	61.2	45.3	45.5	53.8	52.6	61.1	60.1	44.8	45.4
14.0....	50.1	51.2	58.1	59.5	40.9	40.1	51.1	49.6	59.3	57.8	40.1	40.8
14.5....	47.6	47.5	55.6	56.3	35.1	33.2	48.1	45.1	56.2	54.7	36.5	34.4
14.7....	45.4	44.1	54.8	55.1	29.8	—	45.9	42.8	54.8	53.7	—	—
14.8....	42.7	41.3	52.9	52.4	—	—	43.9	39.7	53.1	51.9	—	—
14.9....	39.8	34.8	49.1	47.8	—	—	41.1	33.7	49.4	49.2	—	—
Diameter..	29.85		29.85		29.84		30.00		29.95		29.89	

TABLE I—*Continued*

SERIES IV, SEPTEMBER 8, 1905

ρ	Plate 103. Position I of Diaphragm						Plate 104. Position II of Diaphragm						Plate 105. Position III of Diaphragm					
	¼		½		1		¼		½		1		¼		½		1	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	49.3		55.3		60.1		48.6		54.3		59.6		49.2		55.6		60.1	
4.0....	49.1	48.5	54.8	54.9	60.1	59.1	48.1	47.9	53.7	53.5	59.3	59.2	48.8	48.5	55.2	54.8	59.8	59.8
8.0....	47.8	47.8	54.1	54.5	59.6	58.5	46.7	47.1	52.6	52.5	57.9	57.8	47.1	47.5	54.6	54.3	58.7	59.4
11.0....	45.6	45.9	52.7	52.6	57.8	57.6	45.2	44.5	51.7	51.8	57.2	56.7	45.6	44.8	54.1	52.1	57.8	57.7
13.0....	42.7	42.6	50.1	51.1	54.9	55.5	42.7	40.8	49.6	49.1	55.1	55.1	41.8	42.7	51.1	51.1	57.0	56.2
14.0....	39.6	40.6	48.8	48.6	54.1	53.7	39.3	38.4	49.1	46.8	53.7	53.7	38.7	39.1	49.7	48.7	55.1	55.1
14.5....	36.2	38.7	46.7	46.2	52.6	52.5	34.2	35.4	45.2	45.1	52.3	52.2	35.5	36.2	48.7	46.5	53.7	54.1
14.7....	32.9	34.5	44.9	44.5	51.5	51.1	31.4	32.1	43.7	42.6	50.5	51.0	32.5	32.1	47.3	44.4	52.6	52.5
14.8....	32.1	33.3	44.3	43.7	51.2	50.7	27.5	27.9	43.1	41.6	50.1	50.5	28.6	30.1	46.1	43.7	51.7	52.0
14.9....	22.5	26.4	42.7	41.8	49.1	49.7	—	19.7	41.8	38.9	49.2	49.1	—	21.4	44.1	41.6	50.8	51.2
15.0....	—	16.3	38.2	38.2	46.7	47.1	—	—	37.5	34.6	46.6	45.6	—	—	40.4	34.1	46.5	46.4
Diameter..	30.10		30.10		30.10		30.03		30.07		30.10		30.00		30.10		30.12	

ρ	Plate 106. Position III of Diaphragm						Plate 107. Position II of Diaphragm						Plate 108. Position I of Diaphragm					
	¼		1		½		¼		1		½		¼		1		½	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	52.4		63.2		57.3		52.3		62.5		58.0		53.5		64.1		58.4	
4.0....	52.1	51.7	62.8	62.8	57.1	56.8	52.1	51.8	62.4	62.1	57.6	57.1	53.2	52.3	63.8	63.2	58.2	57.9
8.0....	50.9	50.6	61.3	62.1	56.8	55.9	51.1	50.9	61.3	61.3	56.7	55.6	52.3	51.9	63.1	62.2	57.5	57.3
11.0....	49.3	49.3	60.2	61.1	55.1	54.6	50.1	48.5	59.9	59.8	55.7	55.3	51.1	50.6	61.8	61.1	56.3	55.2
13.0....	46.1	46.1	57.9	59.1	52.3	53.1	46.8	46.9	58.7	57.9	53.6	53.4	48.0	48.2	60.5	59.3	54.9	53.9
14.0....	43.6	42.5	56.1	57.6	50.1	50.1	45.3	44.6	57.0	56.8	51.3	51.3	45.7	46.1	58.7	57.0	53.1	52.1
14.5....	39.1	40.1	54.3	56.1	48.4	48.7	42.4	42.4	55.5	55.5	49.5	49.1	43.8	44.9	57.5	55.7	50.5	50.6
14.7....	37.8	36.8	53.5	55.0	47.2	46.7	41.3	40.2	55.1	54.1	48.3	48.9	41.4	42.1	56.8	54.3	50.1	49.4
14.8....	37.3	35.7	52.8	54.2	45.8	46.2	40.6	38.8	54.1	53.5	47.2	47.5	40.1	41.4	55.7	54.1	48.7	48.3
14.9....	32.6	31.9	51.3	52.8	43.7	43.9	38.9	36.0	53.2	52.1	45.1	46.9	35.8	40.4	54.6	53.2	47.6	46.5
15.0....	29.2	27.3	48.1	50.8	42.5	40.1	32.7	29.1	49.1	49.4	40.1	42.1	31.7	36.2	49.7	50.5	43.1	43.3
Diameter..	30.10		30.10		30.10		30.10		30.10		30.10		30.10		30.10		30.10	

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ρ	PLATE 110. POSITION I OF DIAPHRAGM						PLATE 111. POSITION II OF DIAPHRAGM						PLATE 112. POSITION III OF DIAPHRAGM					
	¼		½		1		¼		½		1		¼		½		1	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	50.8		56.7		60.9		50.4		55.8		60.5		50.6		55.7		59.9	
4.0....	50.3	50.1	55.8	56.1	60.9	61.1	50.2	49.8	55.7	55.2	60.1	60.2	50.1	50.1	55.6	54.7	59.2	59.5
8.0....	49.2	49.4	55.5	55.5	60.1	60.1	49.1	49.0	54.6	54.5	60.0	59.5	49.6	49.3	55.1	54.3	58.8	58.7
11.0....	48.1	47.8	53.7	54.4	58.8	59.4	47.6	46.9	53.2	53.1	58.9	59.1	48.1	47.6	54.3	52.6	58.6	57.7
13.0....	45.6	45.3	51.9	52.7	57.7	58.6	45.6	44.6	52.6	51.1	56.6	57.6	46.7	45.1	51.8	50.9	57.1	55.8
14.0....	43.6	42.1	49.5	50.1	56.1	57.2	43.7	42.2	49.5	49.2	55.1	55.9	44.5	42.2	50.6	48.7	55.6	55.1
14.5....	40.8	40.6	47.6	48.3	54.6	55.1	40.5	39.8	48.2	46.6	54.6	55.1	42.7	40.7	48.7	46.9	54.0	53.3
14.8....	40.3	37.6	44.6	47.1	53.2	54.6	38.2	38.3	46.9	44.8	53.2	53.7	40.5	37.5	47.3	45.5	53.1	52.5
15.0....	32.3	33.2	42.8	44.1	52.1	53.5	37.5	35.5	45.0	43.1	51.8	52.8	39.1	35.4	45.2	43.7	51.7	51.5
15.1....	28.7	28.6	42.2	43.2	51.3	53.1	36.9	33.1	43.7	40.6	51.1	51.4	38.2	32.3	44.6	40.5	51.1	50.1
15.2....	—	25.1	36.6	40.1	45.8	49.1	26.2	23.2	36.6	34.1	43.8	45.5	27.9	20.1	37.6	37.2	44.8	46.1
Diameter..	30.45		30.50		30.50		30.50		30.50		30.50		30.50		30.50		30.50	

To compress these numbers, the mean was then taken for the points equally distant from the center east and west. The values thus obtained were again combined into a mean for each set of similar plates which had been exposed with three different settings of the diaphragm. In this way the following series of values were obtained.

TABLE II

ρ	Plates 66–68			Plates 69–71			Plates 75–77			Plates 78–80		
	1	½	¼	1	½	¼	1	½	¼	1	½	¼
0.0.....	62.4	57.8	52.7	63.5	58.7	53.8	61.0	56.6	52.0	63.6	58.7	53.0
4.0.....	62.1	57.5	52.3	63.0	58.0	53.3	60.3	56.1	50.9	63.2	58.6	52.6
8.0.....	61.3	56.6	51.4	62.3	57.4	52.3	59.7	55.5	50.6	62.4	57.5	51.8
11.0.....	60.3	54.9	49.0	61.3	56.0	50.5	58.5	54.3	49.1	61.0	56.3	50.4
13.0.....	58.1	52.7	46.7	59.5	53.9	47.5	56.6	52.6	47.3	59.1	54.1	48.2
14.0.....	56.2	50.4	42.6	57.7	51.9	45.2	54.8	50.1	45.4	57.3	52.1	46.1
14.5.....	54.8	47.9	39.9	56.1	49.7	42.7	53.2	48.4	43.4	55.1	50.0	44.2
14.7.....	53.6	46.1	37.2	54.9	47.9	40.1	52.1	47.2	42.0	53.9	48.7	42.3
14.8.....	52.7	44.7	34.1	53.6	46.5	38.1	51.0	46.0	41.2	52.9	47.4	41.2
14.9.....	50.2	41.1	—	51.6	43.7	32.2	47.7	43.7	38.9	49.4	43.1	38.2
15.0.....	49.5	—	—	43.6	32.6	—	—	—	—	—	—	—
Diameter	30.02	29.94	29.91	29.94	29.93	29.94	29.84	29.82	29.79	29.84	29.82	29.82

TABLE II—*Continued*

ρ	Plates 87–89			Plates 91–92			Plates 103–105		
	1	½	¼	1	½	¼	1	½	¼
0.0............	63.5	58.2	51.5	65.6	59.6	53.4	59.9	55.1	49.0
4.0............	62.9	57.6	51.1	65.2	59.0	52.9	59.6	54.5	48.5
8.0............	62.3	56.8	49.6	64.3	57.7	51.5	58.7	53.8	47.3
11.0............	61.1	55.1	47.3	63.2	56.3	49.2	57.5	52.5	45.3
13.0............	58.9	52.4	44.4	60.7	53.5	45.3	55.6	50.4	42.6
14.0............	56.1	49.7	40.3	58.7	50.5	40.5	54.2	48.6	39.3
14.5............	54.5	46.5	34.3	55.8	47.1	34.9	52.9	46.4	36.1
14.7............	53.2	43.6	—	54.7	44.6	—	51.6	44.6	32.9
14.8............	52.0	41.7	—	52.6	41.9	—	51.1	43.8	29.9
14.9............	48.2	37.7	—	48.9	37.4	—	49.9	41.9	21.9
15.0............	—	—	—	—	—	—	46.5	37.2	—
Diameter.........	29.93	29.89	29.90	29.90	29.92	29.87	30.11	30.09	30.04

TABLE II—*Continued*

ρ	Plates 106–108			Plates 110–112		
	1	½	¼	1	½	¼
0.0	63.3	57.9	52.7	60.3	56.1	50.6
4.0	62.9	57.5	52.2	60.2	55.6	50.1
8.0	61.9	56.7	51.3	59.6	54.9	49.3
11.0	60.7	55.4	49.8	58.8	53.6	47.7
13.0	58.9	53.5	47.0	57.3	51.9	45.5
14.0	57.2	51.3	44.7	55.9	49.6	43.1
14.5	55.8	49.5	41.8	54.5	47.7	40.9
14.7	54.8	48.8	40.0	—	—	—
14.8	54.1	47.3	39.0	53.4	46.1	38.7
14.9	52.9	45.6	36.0	—	—	—
15.0	49.6	41.9	31.1	52.2	44.0	35.5
15.1	—	—	—	51.4	42.5	33.0
15.2	—	—	—	45.9	37.1	24.6
Diameter	30.10	30.10	30.10	30.50	30.50	30.48

The further problem consisted in determining the relation between the photometer readings and the light-intensities to which the plate was exposed.

We shall express all data as to brightness in astronomical magnitudes. The relation between m and the light-intensity J is defined by the well-known equation:

$$m = -2.5 \log J .$$

Diaphragming down to ½ signifies therefore a loss of light of 2.5 log ½ or 0.753 magnitudes. We will now designate the brightness in the Sun's image at a certain distance from the center with m_1, m_2, m_3, according as the light is diaphragmed down to 1, ½, or ¼. Let the corresponding blackenings (photometer readings) be S_1, S_2, and S_3.

Then we have:

$$m_1 = m_2 - 0.753, \quad m_3 = m_2 + 0.753 . \tag{1}$$

Since the exposure time for all photographs was the same, the blackening is simply a function of the brightness: $S = \Phi(m)$. The following equations therefore obtain:

$$S_1 = \Phi(m_2 - 0.753), \quad S_2 = \Phi(m_2), \quad S_3 = \Phi(m_2 + 0.753) ;$$

or, by inversion,

$$m_2 = \Psi(S_1) + 0.753 = \Psi(S_2) = \Psi(S_3) - 0.753 . \tag{2}$$

The function Ψ is to be determined to satisfy these conditions. This is a problem in interpolation, which we shall treat more fully elsewhere. We now come to our purpose as follows.

Let the three following possibilities be considered:

α) If the relation between magnitudes and opacities were a linear one,

$$m=a-bS\,, \tag{3}$$

it would follow that

$$S_1-S_2=S_2-S_3=\frac{0.753}{b}\,,$$

or the difference of the opacities of corresponding points on the Sun would have to be constant for different degrees of diaphragming.

β) Were the relation between magnitudes and opacities logarithmic,

$$m=\alpha\log(\beta+S)\,, \tag{4}$$

we should have

$$\begin{aligned} S_1&=\beta(\gamma-1)+\gamma S_2\,,\\ S_2&=\beta(\gamma-1)+\gamma S_3\,, \end{aligned} \tag{5}$$

where for abbreviation we place

$$\log\gamma=-\frac{0.753}{\alpha}\,. \tag{6}$$

There would thus be a linear relation between the opacities belonging together.

γ) Finally, let us assume that the function Ψ is of such a nature that its third derivatives may be neglected for the interval S_1 to S_2 or S_2 to S_3. Then we may write, in place of (2)

$$\begin{aligned} 0.753&=\Psi(S_2)-\Psi(S_1)=\Psi'\left(\frac{S_1+S_2}{2}\right)\cdot(S_2-S_1)\\ 0.753&=\Psi(S_2)-\Psi(S_3)=\Psi'\left(\frac{S_2+S_3}{2}\right)\cdot(S_3-S_1)\,; \end{aligned} \tag{7}$$

or, if for brevity we make

$$\frac{S_1+S_2}{2}=T\,,\quad \frac{S_2+S_3}{2}=T'\,,\quad S_2-S_1=D\,,\quad S_3-S_2=D'\,, \tag{8}$$

$$0.753=\frac{d\Psi}{dT}D=\frac{d\Psi}{dT'}D'\,.$$

By integrating, we obtain

$$\Psi(T)=0.753\int^T\frac{dT}{D}=0.753\int^T\frac{dT'}{D'}\,. \tag{9}$$

We therefore have to treat the reciprocal difference of the related opacities as a function of the mean T of the two opacities, and to integrate in order to obtain the desired function Ψ — the magnitude m belonging to each opacity T. The constant of integration—i. e., the starting-point for computing magnitudes—remains undetermined and a matter of indifference.

The three possibilities just described will in general give the necessary means of determining the function Ψ.

In our case the procedure was as follows:[1] It is easy to see that the related values of the opacities S_1, S_2, S_3, which in Table II are placed next each other, to some extent progress in a linear fashion. If we choose the coefficients β and γ in the relations (5) so that the actual dependence of the opacities is approximately reproduced, and if we then compute for each opacity S a quantity s by the formula

$$s = a \log (\beta + S) , \tag{10}$$

then this quantity s will represent a sort of corrected opacity which will correspond very closely to the magnitudes. If we therefore seek further for the precise relation between s and the magnitude m; $m = \psi(s)$. Then we can make the assumption mentioned under γ, that the higher derivatives of ψ may be neglected, and therefore we may find ψ corresponding to (8) and (9) by forming

$$t = \frac{s_1 + s_2}{2} , \quad t' = \frac{s_2 + s_3}{2} , \quad s_2 - s_1 = \Delta , \quad s_3 - s_2 = \Delta' , \tag{12}$$

$$\psi(t) = 0.753 \int^t \frac{dt}{\Delta} = 0.753 \int^t \frac{dt'}{\Delta'} . \tag{13}$$

In practice the following small modification of this scheme was found necessary. (13) gives two independent determinations of the function ψ, one from the exposures with diaphragms 1 and $\frac{1}{2}$, a second from those with diaphragms $\frac{1}{2}$ and $\frac{1}{4}$. There almost always appeared to be a small systematic difference between the two determinations of the function ψ, due to the fact that the sectors of the diaphragms have not precisely the prescribed dimensions; an exact

[1] The relation between magnitudes and opacities was too far from being linear in the case of several plates to make it advisable to use the simple adjustment employed in our previous communication. We therefore preferred to use the more inconvenient but systematic reduction throughout.

measurement of the sectors used by us yielded the actual values of 0.767 and 0.759 mag.; and that further differences arise from a change in the transparency of the air or in the velocity of the shutter. We shall therefore assume that the true values of the degree of diaphragming from 1 to $\frac{1}{2}$ and from $\frac{1}{2}$ to $\frac{1}{4}$ equal certain values a and b, and that only the total difference between the diaphragming for 1 and $\frac{1}{4}$ equals the prescribed values 0.767 and 0.759. In other words, we assume in place of (1)

$$m_1 = m_2 - a\,, \quad m_3 = m_2 + b\,, \quad a + b = 1.527 \text{ mag.} \tag{14}$$

We therefore have in place of (13)

$$m = \psi(t) = a\int^t \frac{dt}{\Delta} = b\int^t \frac{dt'}{\Delta'}\,. \tag{15}$$

Hence for the differences Δ and Δ' which pertain to equal values of t and t',

$$\frac{\Delta}{a} = \frac{\Delta'}{b}\,. \tag{16}$$

The ratio $\frac{a}{b}$ is therefore to be determined from the average ratio of the differences Δ and Δ'.

In the actual employment of this process the differences Δ and Δ' were entered as the ordinates for the abscissae t and t' in the same figure, which gave two different curves. The ordinates of the second curve were then enlarged in a ratio $\frac{a}{b}$, which brought the two curves into the best possible conformity; and finally a new curve was drawn which followed the mean position between the first curve and the second curve enlarged. From this the differences Δ were then taken off as functions of t, and then by the first of the formulæ (15) m, the function sought, was computed by mechanical quadrature.

We give as an example to render clear the whole process, the group of Plates 66 to 68 in the second and fourth column of Table II. By graphically entering S_1 as a function of S_2, and S_2 as a function of S_3, it was found that with some degree of approximation the following linear relations held good:

$$S_1 = 0.755\, S_2 + 18.14 \text{ and } S_2 = 0.755\, S_3 + 18.14\,.$$

The comparison with (5) and (6) gives

$$\beta(\gamma-1)=18.14\;;\quad \gamma=0.755\;;\quad a=-\frac{0.753}{\log\gamma}\;;$$

whence

$$\beta=-74.0\;;\quad a=6.18\;.$$

And therefore by (10) $s=6.18\log(S-74.0)$. A "corrected" opacity s was now computed by this formula for every opacity S, with the resulting values s_1, s_2, s_3, given in the following table (for convenience all have been diminished by 6.18):

ρ	s_1	s_2	s_3	t	Δ	t'	Δ'	From Curve t	From Curve Δ
0.0	0.40	1.30	2.03	0.85	0.90	1.66	0.73	0.8	0.900
4.0	0.47	1.35	2.08	0.91	.88	1.72	.74	1.0	.870
8.0	0.64	1.49	2.19	1.07	.84	1.84	.70	1.2	.850
11.0	0.85	1.74	2.46	1.29	.89	2.10	.72	1.4	.830
13.0	1.24	2.03	2.69	1.63	.79	2.36	.66	1.6	.805
14.0	1.54	2.30	3.07	1.92	.76	2.69	.77	1.8	.785
14.5	1.75	2.58	3.29	2.16	.83	2.94	.71	2.0	.790
14.7	1.92	2.76	3.50	2.34	.84	3.13	.74	2.2	.810
14.8	2.03	2.89	3.71	2.46	.86	3.30	.82	2.4	.830
14.9	2.33	3.19		2.76	.86			2.6	.840
15.0	2.40							2.8	.855
								3.0	.855

The mean values t and t', and the appropriate differences Δ and Δ' of the consecutive values of s, were now formed. The graphical process described above gave $\frac{\Delta}{\Delta'}=\frac{a}{b}=1.14$; $a=0.814$ mag.; $b=0.713$ mag.; and the smoothed-out values of Δ given in the table. Then the first integral of (15) was formed simply by the trapezoidal rule, which yielded the function ψ sought for. The following table for ψ resulted:

s	$m-\psi(s)$	s	$m-\psi(s)$
0.4	2.59 mag.	2.0	1.08 mag.
0.6	2.42	2.2	0.87
0.8	2.26	2.4	0.67
1.0	2.07	2.6	0.48
1.2	1.88	2.8	0.29
1.4	1.69	3.0	0.10
1.6	1.49	3.2	−0.09
1.8	1.29	3.4	−0.27

With this we could finally convert the values s_1, s_2, s_3, into magnitudes. The results were as follows:

ρ	m_1	m_2	m_3	m_1-m_2	m_2-m_3
0.0	2.59	1.79	1.03	0.80	0.76
4.0	2.53	1.74	1.00	.79	.74
8.0	2.38	1.60	.88	.78	.72
11.0	2.21	1.35	.61	.86	.74
13.0	1.84	1.05	.37	.79	.68
14.0	1.54	0.76	.03	.78	.73
14.5	1.34	0.50	−.17	.84	.67
14.7	1.17	0.33	−.37	.84	.70
14.8	1.05	0.20	−.56	.85	.76
14.9	0.74	−0.09		.83	
15.0	0.67				

The differences m_1-m_2 and m_2-m_3 have, in fact, become constant within the limits of accidental errors, which confirms the fact that the opacities corresponding to the conditions (14) are thus transformed into magnitudes.

If desired, the value s can subsequently be rejected, as that only constitutes an intermediate step, and by a combination of (10) and the table for $\psi(s)$, a table may be constructed by which we may pass directly from the opacities S to magnitudes. This procedure was employed in what follows. Table III contains the

TABLE III

S	Plate Numbers								
	66–88	69–71	75–77	78–80	87–89	91–92	103–105	106–108	110–112
	mag.	mag.	mag.	mag.	mag.	mag.	mag.	mag.	mag.
66						2.48			
62	2.51	2.76	3.43	2.64	2.25	1.86		2.64	3.64
58	1.82	2.10	2.76	2.04	1.69	1.37	2.39	2.05	2.80
54	1.23	1.52	2.08	1.46	1.22	0.94	1.80	1.47	2.13
50	0.72	1.03	1.45	0.91	0.80	0.55	1.28	0.98	1.63
46	0.33	0.61	0.82	0.38	0.46	0.24	0.86	0.58	1.19
42	−0.01	0.24	0.17	−0.12	0.17	−0.02	0.52	0.22	0.82
38	−0.31	−0.05			−0.08	−0.28	0.26	−0.06	0.49
34	−0.57	−0.31			−0.27	−0.48	0.06	−0.31	0.21
30							−0.07	−0.54	−0.03
26							−0.18		−0.23
22							−0.27		−0.42
a	0.814	0.825	0.724	0.730	0.763	0.837	0.730	0.784	0.834
b	0.713	0.702	0.803	0.797	0.764	0.690	0.797	0.743	0.693

transformation table of the opacities into magnitudes for all the groups of plates. The values of *a* and *b* obtained are given every time at the foot of the table, which gives a certain insight into the trustworthiness of the diaphragming.

Thus all the data needed for the reduction of the plates are given.

III

With the aid of the above tables all of the opacities given in Table II were converted into magnitudes. The numbers in each column were then subtracted from the number at the head of the column, which corresponded to the brightness at the Sun's center, so that the resulting differences gave directly the decrease in the brightness of the Sun from the center. The mean was taken of the three series of numbers resulting for each group. Thus the conversion of the opacities into magnitudes furnished for the group of plates 66–68 the three series given above for m_1, m_2, m_3. The subtraction from the number at the top of each column yielded the values M_1, M_2, M_3, the mean of which is given under M.

ρ	M_1	M_2	M_3	M
0.0	0.00	0.00	0.00	0.00
4.0	0.06	0.05	0.03	0.05
8.0	0.21	0.19	0.15	0.18
11.0	0.38	0.44	0.42	0.41
13.0	0.75	0.74	0.66	0.72
14.0	1.05	1.03	1.00	1.03
14.5	1.25	1.29	1.20	1.25
14.7	1.42	1.46	1.40	1.43
14.8	1.54	1.59	1.59	1.57
14.9	1.85	1.88		1.87
15.0	1.92			1.92

A final correction is to be applied to these measures on account of the varying diameter of the Sun's image. As may be seen from the data at the foot of Table II, the weakest image was smaller by 0.02 mm or 1'.3, the strongest image larger by a similar amount than the average image. The impression is in fact given that, with diaphragm $\frac{1}{4}$, the Sun's limb is not quite sufficiently exposed, that the image with full aperture may suffer a little from irradiation on the film, and that the mean image yields the most trust-

worthy value of the diameter. On these images the edge is sharply defined to 0.01 mm under the microscope, and just outside the disk there is clear glass. The diameter of the image from the diaphragm ½ is therefore taken as the standard, and its mean value for each group is used, as given at the foot of Table II; for instance, 29.94 for the group 66–68. With this the distances from the center of the disk, ρ, were converted into decimals of the Sun's radius. Finally the brightnesses were interpolated for the arbitrarily chosen standard value x of the distance from the center.

A similar treatment of all the groups of plates yielded the following nine series of values, the mean of which is to be regarded as the final result of this investigation. The differences from the mean are added, and the last column gives the light-intensity corresponding to the difference in magnitude, the intensity of the center of the disk being taken as unity.

TABLE IV

x	66–68	69–71	75–77	78–80	87–89	91–92	103–106	106–108	110–112	Mean
										mag.
0.000..	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
0.267..	0.05	0.09	0.13	0.05	0.07	0.06	0.06	0.06	0.05	0.070
0.533..	0.18	0.20	0.21	0.18	0.18	0.21	0.19	0.18	0.16	0.188
0.733..	0.40	0.39	0.42	0.38	0.38	0.38	0.38	0.37	0.36	0.384
0.867..	0.70	0.70	0.69	0.65	0.64	0.68	0.64	0.63	0.63	0.662
0.933..	1.01	0.95	1.01	0.91	0.94	0.95	0.86	0.89	0.91	0.937
0.967..	1.23	1.18	1.29	1.20	1.18	1.25	1.07	1.13	1.15	1.187
0.980..	1.38	1.35	1.45	1.34	1.33	1.36	1.23	1.26	1.34	1.338
0.987..	1.57	1.49	1.54	1.43	1.45	1.51	1.34	1.39	1.45	1.457
0.993..	1.75	1.74	1.72	1.60	1.65	1.76	1.58	1.64	1.64	1.676
0.997..	1.93	1.92	1.92	1.81	1.82	1.94	1.76	1.83	1.96	1.877

Differences from the Mean (Unit 0.01 mag.)									Mean Error	y
66–68	69–71	75–77	78–80	87–89	91–92	103–106	106–108	110–112		
									mag.	
0	0	0	0	0	0	0	0	0	0.000	1.000
−2	+2	+6	−2	0	−1	−1	−1	0	0.008	0.938
−1	+1	+2	−1	−1	+2	0	−1	−3	0.005	0.841
+2	+1	+4	0	0	0	0	−1	−2	0.006	0.702
+4	+4	+3	−1	−2	+2	−2	−3	−3	0.010	0.544
+7	+1	+7	−3	0	+1	−8	−5	−3	0.017	0.422
+4	−1	+10	+1	−1	+6	−12	−6	−4	0.024	0.335
+4	+1	+11	0	−1	+2	−11	−8	0	0.019	0.292
+5	+3	+8	−3	−1	+5	−12	−7	−1	0.021	0.261
+7	+6	+4	−8	−3	+8	−10	−4	−4	0.023	0.214
+5	+4	+4	−7	−6	+6	−12	−5	+8	0.024	0.178

In regard to the question of the reliability of these values, if the precision of the double settings of the Hartmann micro-photometer be taken as 2 per cent., a mean error of 0.002 mag. would result from the measures of the seventy-eight plates. It is evident at a glance that this precision of settings is rendered illusory by systematic differences in the blackening on the plates. For example, a comparison of the corresponding numbers in Table I for the east and west sides of the Sun shows a systematic excess, first on one side, then on the other. Since the mean of all the images shows an almost perfect symmetry in the two halves, the differences do not originate in the Sun, but in the plate or the photographic process. The causes which have a systematic effect on a single plate seem to affect different plates in a purely accidental manner. At least we are unable to trace any law in the differences found by comparing the east and west halves of the Sun or the values a and b.

Under these circumstances an idea of the trustworthiness of the above quantities can be gained from the differences in the nine series. These yield the mean errors given in the next to last column, which reveal the increasing uncertainty with the increase of the observed difference in brightness. The systematic enlargement of the differences in the greater part of the numerical values can be explained from the uncertainty of the scale-value a. From the deviations of the values of a given in Table III from the prescribed value we should derive, with the method of reduction employed, the mean error of the final value of $\pm 0.013\, M$ mag., where M is the difference of magnitude to be measured; and for the effect of other accidental circumstances there would remain a mean error of only ± 0.009 mag. It is probable, all things considered, that an accuracy is attained equal to that of Vogel's measures in the visible spectrum. Furthermore, the decrease in brightness is followed nearer to the limb than by previous observers. While Very's measures stopped at 0.95 and Vogel's at 0.97, there is no reason for doubting that the values obtained for $x=0.980$, 0.987, and even 0.993 are real expressions of the Sun's brightness at those distances from the center of the disk. This will scarcely apply to $x=0.997$, for at this point, in addition to the difficulties of measurement, irradiation in the film and errors in definition

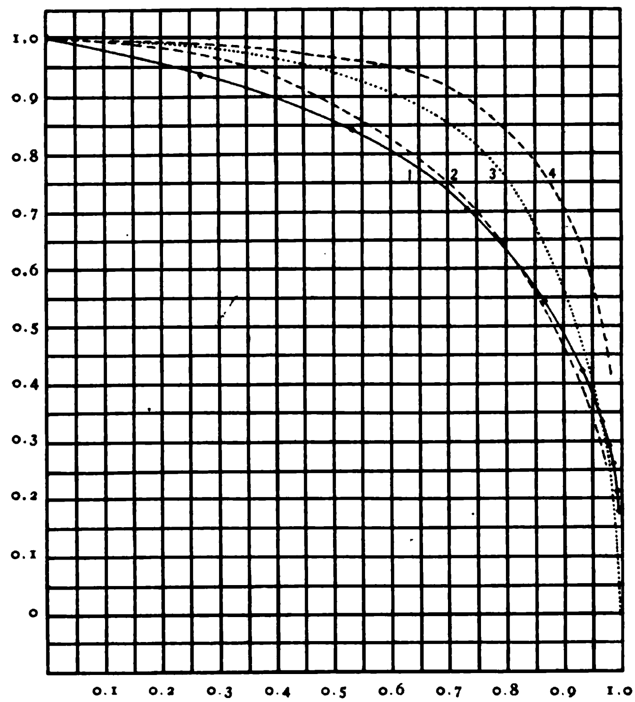
of the objective amounting to a second of arc might affect the result.

We must finally meet one more objection, that the decrease in the Sun's brightness from the center of the disk might be rendered inaccurate by the instrument itself. A simple consideration shows that the absorption in the objective and in the silver films does not change appreciably when the inclination to the axis is increased to 15′ (the Sun's radius). At first thought there would seem to be much more danger from the secondary images arising from the double reflection at the silvered surfaces. But, on the one hand, the experiments of E. Hagen and H. Rubens[1] show that the reflecting power of silver in the region solely to be considered here (from λ 315–327 $\mu\mu$) lies below 15 per cent., so that for an image arising from double reflection only 2 per cent. remains. On the other hand, we have also a direct check on this effect. A computation from the known optical constants of the objective showed that the image resulting from the reflection of the two silvered surfaces, which at the same time is the nearest of all the reflected images to the focal plane, lies 85 cm behind that plane. A halo 16 mm wide would thereby be produced around the focal image of the Sun. Its intensity at a distance of 2 mm from the Sun's limb would come out as about 0.2 of the central brightness of the real solar image, if no light was lost by reflection, and if the distribution of brightness on the Sun's disk found above is taken as our basis. Two photographs of the Sun were now made on the same plate, the objective being diaphragmed down to 10 mm and 5 mm respectively; and, moreover, a third exposure with full aperture, for which, however, the image of the Sun itself was covered up by a metal disk placed immediately in front of the plate and extending 2 mm beyond the Sun's limb. The time of exposure was in each case 10 seconds. The comparison of the opacities yielded the result that the brightness at 2 mm distance from the Sun's limb amounted to 0.0008 of the central brightness of the Sun. The brightness of the reflex image must therefore be weakened by the double reflection at least in the ratio 0.0008:0.2 or 0.004:1, and therefore cannot in fact come into consideration.

[1] *Zeitschrift für Instrumentenkunde*, **22**, 42, 1902.

IV

We will now compare the results we have obtained for $\lambda=0.320$ with those for other wave-lengths. In the diagram the values of J/J_0 for $\lambda=0.320$ are shown in connection with the curves obtained by Vogel for the red and violet. The noteworthy result to be derived from these curves is this: The decrease of the brightness is not



1, $\lambda=0.322\,\mu$; 2, $\lambda=0.409\,\mu$;
3, Earth's atmosphere; 4, $\lambda=0.662\,\mu$.
+observed points.

more marked in the ultra-violet than in the violet; the gradual increase in the rate of falling off which is observed in passing from the red toward the violet, comes to a stop in the ultra-violet. If we were to regard as real the small difference of the curves for $\lambda=0.320\,\mu$ and $\lambda=0.409\,\mu$, then we should have to say that in the ultra-violet the decrease, at first stronger than in the violet, is checked on approaching the limb, and finally becomes even less than for the violet.

This behavior directly contradicts the analogy with the Earth's atmosphere, in which the absorption increases very rapidly toward the ultra-violet. This new fact should be added to that noted by Vogel: the shape of the curve does not follow the laws valid for the Earth's atmosphere. The dotted curve shows the distribution in intensity which would be found in the Earth's atmosphere viewed from without, if the surface were a self-luminous black body (calculated by doubling the Potsdam extinction table). The differing character of the decrease is noticeable, especially for the ultra-violet.

Explanation of this difference in curves can be attempted in two different ways. Seeliger[1] ascribes to the Sun's atmosphere a refractive index differing much more from unity than that possessed by the Earth's atmosphere. Schuster[2] takes into account the radiation from the Sun's atmosphere itself. The theoretical treatment of our observations with reference to such views we desire to reserve for another occasion.

We intend to continue the measures in order to obtain data as to a possible variation in the absorption of the solar atmosphere.

GÖTTINGEN AND JENA,
January 1906.

[1] *Sitzungsberichte der bayrischen Akademie der Wissenschaften*, **21**, 1891.

[2] *Astrophysical Journal*, **16**, 320, 1902.

A NEW METHOD FOR THE DISCOVERY OF ASTEROIDS

By JOEL H. METCALF

During the past four months I have put into practice a method for the photographic discovery of asteroids which has worked so well that perhaps a description of it may interest the readers of the *Astrophysical Journal.*

The old method which Professor Max Wolf has used with such wonderful success is to take a long-exposure photograph of the region to be examined, and then search the plate for trails made by the moving planets. When the asteroids are in opposition, they retrograde on an average about 34″ an hour. This on the plate of a large portrait-lens is quite an appreciable amount, and just in proportion as the objective has a longer focus, the trails become longer, and hence, other things being equal, make a fainter impression on the plate. It was on this account that the old-fashioned portrait-lens of the Petzval type was found so satisfactory. First, it gave a large field which would be important in any case; second, it gave a very short focus with great light-collecting power. So it happens that in a system of lenses of the portrait type the brilliant image would be held on the same part of the plate longer than it would have been with a lens of the same aperture, but greater focal length. As a result of this, fainter asteroids could be photographed than with the lens of longer focus.

Stars of extremely low magnitude can be photographed with very small lenses, if only the exposure time is lengthened. With asteroids, which are moving on the plate, however, if no impression is made in a given time—and that a short one—no effect will ever be produced. For illustration, in my 12-inch objective the size of the fainter star-images with an hour's exposure is 4″ to 5″. An asteroid at opposition therefore would move the diameter of a star-image in less than ten minutes. This implies that if its image is not impressed upon the plate in about ten minutes, it never will be.

It is evident, therefore, that if any method could be devised

so that the asteroids could be made stationary in reference to the plate so that longer exposures could be given, much fainter ones could be photographed. This principle has been utilized for many years in the photography of comets, and more recently Professor Bailey, of Harvard Observatory, photographed *Eros* soon after conjunction with the Sun by moving the plate to overcome the computed movement of the asteroid.

This general principle I have applied with success to the discovery of asteroids. It is just the opposite of Wolf's method, for he follows the stars so that they are points on the photographic plate and the asteroids are trails, while I have followed the asteroids and the stars are trails. This principle, which is clearly applicable to known objects, might at first sight seem to be useless for unknown objects whose movements are unknown. An inspection of the *Berliner Jahrbuch*, which gives the positions and daily motions of asteroids as they come to opposition, would, however, lead to an opposite opinion. Take for illustration the known asteroids for the first two weeks of April 1906. There are seventeen asteroids predicted to come to opposition during that time. Their average hourly motion in R. A. is —34″. The greatest motion is 41″, and the least 26″, which differ from the mean by 7″ and 8″ respectively. It is thus seen that if the photographic plate were moved 34″ an hour in the proper direction, it would follow them all within the diameter of a little over the size of a star-image and the great majority of them much more closely still. In declination the same asteroids are predicted to move on an average +10″ per hour, the greatest motion is +17″ and the least 0″. These differ from the mean 7″ and 10″, respectively. In an hour, therefore, if all the asteroids happened to fall on the same plate at the same time, they could all be followed (with the exception of one) *for an hour* within about the diameter of a star-disk. In other words, by properly moving the plate the length of effective exposure could be lengthened for them all from 10 minutes under the old method to 30 minutes, and for the majority of them to an hour or more, simply by moving the plate the amount which an average asteroid is expected to move.

In practice what I do is to place my filar micrometer on the visual

telescope, which is rigidly bound to the photographic telescope. I then obtain the east-and-west direction in the usual way by making a star follow the wire. At this point I revolve the micrometer-head in position angle, north or south as the case may be, to bring it parallel to the ecliptic, which of course is the direction of motion of the ideal mean asteroid on that date. Then I set on a star for following which is in the middle of the region I wish to examine, and the exposure begins. Every minute I turn the micrometer-head the amount of the computed mean motion and with the slow motions in right ascension and declination bring the star back to the cross-wires. This may seem to be a very tedious process, but I do not find it so. If one has to be watching the cross-wires to correct the clock and for refraction, he might as well do something else between times. Minutes almost seem like seconds when one is busy setting up the micrometer-head and bringing the star back to position.

At the end of 35 minutes' exposure, which I have found in practice sufficient to give images down to 13.5 magnitude and lower, I close the shutter of the photographic telescope and move the micrometer-wire 25″ or 30″, and then take another similar exposure of the same length. It can at once be seen that when the plates come to be developed, every star bright enough to be photographed will be represented by two trails whose length will depend upon the exposure-time, but will be equal to the amount which a mean asteroid should move in that time. Then between the trails will be the arbitrary separation given them between exposures. If there are any asteroids in the field, on the other hand—and it very rarely happens that there are none—their images will be like two points (or normal star-images) separated by the same space as the star-trails. In practice I find that the two exposures are much more satisfactory than one, as it makes it impossible to be misled by an imperfection in the film. It is the same kind of a check which Dr. Wolf accomplishes by using two telescopes and taking two plates of the same region.

The chief points of excellence which I would claim for this method are these:

First, the remarkable images which one in practice obtains—most of the asteroids come out astonishingly round and clear-cut.

Fig. 1

Fig. 2

Fig. 3

Photographs of Asteroids

Second, the ability to photograph very faint asteroids with a comparatively small lens. The gain over the old method in an hour's exposure must certainly be at least 2 magnitudes. In practice I have not failed to find the faintest asteroids of the *Berliner Jahrbuch*.

Third, it gives an image capable of more accurate measurement. In the old way the asteroids were usually measured by bisecting the trails on the plate, and taking that as the position at the middle time. As the trails were usually faint, slight differences of the transparency of the atmosphere between the beginning and end of the exposure would tend to shorten one end of the trail so the middle of the actual trail would not be the position of the asteroid at the middle time. Under the new method the asteroid is capable of measurement with all the accuracy of an ordinary star-image. The stars, on the other hand, are trails, but only the brighter ones could be used as reference stars for measurement, and hence slight changes of transparency of the air would not effect them. Then again any number of star-trails one pleases can be measured and a good mean position obtained.

Referring to the illustrations of this article, which are enlargements of plates taken in the way described, each pair of trails is a star, and each pair of points is an asteroid.

Fig. 1 is a bright known asteroid (17) *Thetis* of magnitude 10.6.

Fig. 2 shows a new asteroid of about the thirteenth magnitude discovered here on March 22, 1906.

Fig. 3 is 1905 *S H*, whose magnitude is 13.5. As may be seen from the plate, this asteroid was moving rapidly north (6′ per day) when the ecliptic was east and west; it is, therefore, an extreme case. Circular elements show it to have an inclination of 25° to the ecliptic. Yet it is evident that I could never have photographed it in the old way, as the extreme faintness of the short trail shows. Its motion differed widely from the mean asteroid, but it justified the method.

My attention has just been directed to the fact that in *Astronomische Nachrichten* (**144**, 331, 1897) Professor E. E. Barnard has an article on a proposed instrument for accurately photographing an unseen moving but known celestial body. In description

of it he says: "To accomplish this it is only necessary to have the guiding cross-wires attached to a light frame which can be moved by a delicate clock-work, the speed of which can be regulated to the motion of the object. This is also to be arranged so that its direction of motion can be adjusted in any position angle." He suggests the works of an ordinary watch with necessary gearing so that the speed may be regulated. "The instrument having been placed on the eye-end of the guiding telescope, it is carefully set so that the amount and direction of motion of the cross-wires shall coincide with that of the comet or minor planet." A star in the field is then followed by being kept continuously on the cross-wires by the slow motions in the usual way, but owing to the motion of the cross-wires the comet or asteroid will remain perfectly stationary on the plate.

TAUNTON, MASS.,
April 1906.

A NEW METHOD FOR DETERMINING THE RATE OF DECREASE OF THE RADIATIVE POWER FROM THE CENTER TOWARD THE LIMB OF THE SOLAR DISK

By W. H. JULIUS

The brightness of the solar disk is known to diminish considerably from the center toward the limb. Although this prominent feature of the solar phenomenon should be among the first accounted for in every theory of the Sun, it leads to problems presenting so many difficulties that a satisfactory explanation is, until now, altogether wanting. And even the empirical study of the law according to which the radiating power varies across the disk is not very advanced.

What we know about the question is founded on researches in which either a photometer or a thermopile, a bolometer or a radio-micrometer, was used for exploring an *image* of the Sun. The results obtained by different observers are rather discordant.[1] This may be partly due to instrumental or accidental errors, but there is also a systematic error which must have influenced similarly all of the results thus obtained, and which proceeds from the scattering of the rays by the terrestrial atmosphere. In any point of an image of the Sun is not only to be found the radiation coming from the corresponding point of the disk, but, in addition, some diffused radiation proceeding from other parts of the disk. This disturbing effect will, of course, vary in magnitude with the condition of the atmosphere, but it will always act in a leveling way, parts of the image lying near the edge receiving more diffused radiation from the middle parts of the disk than the central parts of the image receive from the edge parts of the disk.

We may completely avoid this source of error by using a method in which the radiating power of the different parts of the disk is calculated from observations made on the occasion of a total eclipse of the Sun.

[1] Cf. J. Scheiner, *Strahlung und Temperatur der Sonne*, pp. 43–49, 1899.

Let us suppose the curve representing the intensity of the solar radiation from the first until the fourth contact as a function of time, to be exactly known.[1] The curve will show us by how much the total radiation has increased or decreased between any two epochs. Every (positive or negative) increment is exclusively due to rays coming from that strip of the solar disk through which the Moon's limb has appeared to move between just those epochs.

Suppose the time after third contact to be divided into equal intervals of, say, two minutes, and the position of the Moon's limb at the end of each interval delineated on the solar disk, then the latter will be divided into thirty-nine narrow strips, successively contributing the ***known*** quantities a, b, c, d . . . . to the total radiation.

Now, let us distinguish n concentric zones on the solar disk and denote by $x_\alpha, x_\beta, \ldots . x_\nu$ the radiation coming from these zones per unit surface. (In accordance with the results obtained by Langley and by Frost, we shall suppose the radiating power to vary only with the distance from the center, not with the position angle.) One of the strips will contribute to the radiation

$$d=\delta_1 x_\alpha+\delta_2 x_\beta+\ldots . \delta_n x_\nu$$

if it cuts out of the first zone an area δ_1, out of the second zone an area δ_2, etc. The next strip contributes:

$$e=\epsilon_1 x_\alpha+\epsilon_2 x_\beta+\ldots . \epsilon_n x_\nu$$

and so on. We get thirty-nine equations from which $x_\alpha, x_\beta, \ldots x_\nu$ may be resolved.

DETERMINATION OF THE COEFFICIENTS OF THE n UNKNOWN QUANTITIES

I have found the coefficients $\delta_1, \delta_2, \ldots . \epsilon_1, \epsilon_2$, by . . . . weighing. On a piece of excellent homogeneous paper the solar disk was drawn and divided into a suitable number of concentric zones, which were intersected by arcs representing the Moon's limb in its successive positions. The following astronomical data,

[1] It is well known that, at Burgos, the observation of the eclipse of August 30, 1905, was not favored by a clear sky. (Cf. the Preliminary Report in the *Proceedings Royal Acad. Amsterdam*, **8**, 501, 1905.) Nevertheless, the measurements of total radiation have yielded some results of sufficient accuracy to justify in our present investigation, the use of the radiation-curve then secured. Further particulars regarding the observations will soon be published in the complete report on our expedition.

necessary for making the drawing, have been kindly procured for me by Professor A. A. Nyland.

Contact	I	II	III	IV
Position angle	293°.4	104°.5	304°.9	114°.9
Local time	$23^h\ 33^m\ 10^s$	$0^h\ 51^m\ 58^s$	$0^h\ 55^m\ 39^s$	$2^h\ 12^m\ 14^s$

Moon's radius: Sun's radius = 132.8 : 126.8.

Now the strips were carefully separated from each other and weighed (for subsequent control). Then each strip was cut along the zone-circles, and the pieces were weighed separately. In order to make the pieces recognizable, the zones had all been differently painted, each with a narrow line of water-color. The weighings, which were accurate to half a milligram, gave the coefficients of the unknown quantities x_α, x_β . . . . x_ν. So the unit of area, adopted for measuring the surface of the solar disk, corresponds to a piece of our drawing-paper weighing 1 milligram.

The breadth of each of the outer five concentric zones was 1/20 of the Sun's radius; then came seven zones with breadth 1/10 of the radius, each leaving around the center a circle with radius 1/20. The average distances of the zones from the center, expressed in thousandth parts of the radius, will now be used as indices α, β, ... of our thirteen unknown quantities; so these will be written:

$$x_{975},\ x_{925},\ x_{875},\ x_{825},\ x_{775},\ x_{700},\ x_{600},\ x_{500},\ x_{400},\ x_{300},\ x_{200},\ x_{100},\ x_0\ .$$

On p. 316 the equations are written out. We have confined ourselves to thirteen equations; increasing this number would not have led to greater accuracy, as the values of a, b, c, . . . had to be found from the radiation-curve—that is, by graphical interpolation—in which process it is understood that *all* of the observations have already been taken into consideration.

DETERMINATION OF THE CONSTANT TERMS OF THE EQUATIONS

Table I contains the results of the observations made at Burgos with our actinometer. The second column gives the galvanometer deflections, from which are calculated the numbers of the

TABLE I

	Time	Galvanometer Deflections	Intensity of Radiation		Time	Galvanometer Deflections	Intensity of Radiation
	$22^h\ 28^m\ 48^s$	280.0	1,750,000		$0^h\ 20^m\ 48^s$	128.5	819,000
	36 0	231.0	1,444,000	2d contact	51 58		
	38 33	287.0	1,794,000		53 53	3.0	9
					54 28	13.0	13
	46 58	287.0	1,794,000		55 18	33.0	33
	51 38	270.0	1,688,000	3d contact	55 40		
	53 49	260.5	1,631,000		55 58	600.0?	600?
	56 8	278.5	1,745,000		57 58	118.5	23,000
					58 33	98.5	19,100
	23 4 58	256.0	1,610,000		59 13	219.5	42,700
	8 3	283.5	1,786,000		59 53	286.0	55,700
	9 56	284.5	1,792,000		1 1 18	232.5	74,800
	11 44	275.0	1,736,000		2 28	170.0	108,800
1st contact	33 8				3 3	152.5	97,700
	35 48	226.0	1,430,000				
	38 3	256.5	1,625,000		7 38	323.5	207,000
	40 38	269.5	1,709,000				
	41 38	270.0	1,712,000		21 15	331.5	635,000
	42 48	270.5	1,715,000		22 3	347.5	665,000
	44 0	260.0	1,649,000		23 3	151.5	676,000
	45 33	259.5	1,646,000		23 58	162.0	722,000
	46 38	256.5	1,627,000		24 53	167.0	745,000
	47 52	248.5	1,566,000		25 53	174.0	776,000
	48 53	250.5	1,589,000		26 53	180.5	805,000
	50 8	249.0	1,580,000		27 53	186.5	832,000
	51 33	241.0	1,529,000		28 58	194.0	865,000
	53 8	233.5	1,483,000		30 8	201.0	897,000
	55 3	227.0	1,442,000		31 8	207.5	926,000
	56 33	226.0	1,435,000		32 11	213.0	950,000
	50 23	216.5	1,376,000		33 13	220.0	981,000
					34 20	225.5	1,007,000
	0 7 23	192.0	1,222,000		35 25	232.5	1,037,000
	8 53	184.0	1,170,000		36 34	237.5	1,060,000
	10 28	177.0	1,127,000				
	11 43	171.5	1,091,000		2 1 58	338.0	1,506,000
	13 13	165.5	1,054,000		3 8	248.0	1,581,000
	14 58	159.0	1,013,000	4th contact	12 24		
	17 3	150.0	956,000		13 18	258.5	1,648,000
	19 28	136.0	867,000		14 20	260.0	1,657,000

third column, representing the intensity of the radiation.[1] Owing to the clouds, there are large gaps in the series of observations but

[1] Particulars concerning the connection between the numbers of these two columns will be found in the forthcoming report on the Dutch expedition. The method and the instruments used at Burgos were the same that are described in "Total Eclipse of the Sun, May 18, 1901: Reports on the Dutch Expedition to Karang Sago, Sumatra; No. 4: Heat Radiation of the Sun during the Eclipse," by W. H. Julius. The numbers of the third column are proportional to the total radiation coming from a circular patch of the sky, 3° in diameter, with the Sun in its center.

nevertheless, after the results had been plotted, we saw that there was only little room left for fancy when drawing the radiation-curve in such a way that closest agreement with the observational data was obtained. As a matter of course, the curve has not been drawn *between the series of points, but so as to join the highest points*, for the observed values could only be too small. Only one exception is made to this rule, the value found at $0^h\ 17^m\ 3^s$ being very probably too high by some error or instrumental disturbance.

$a = 126\ x_{975}$
$b = 66x_{975} + 101x_{925}$
$c = 28x_{975} + 59x_{925} + 84x_{875} + 1x_{825}$
$d = 18x_{975} + 29x_{925} + 50.5x_{875} + 77x_{825} + 1.5x_{775}$
$e = 13x_{975} + 19x_{925} + 27.5x_{875} + 46x_{825} + 69.5x_{775} + 2x_{700}$
$f = 10x_{975} + 14x_{925} + 19x_{875} + 28x_{825} + 40x_{775} + 66x_{700}$
$g =$
$h = 8x_{975} + 10x_{925} + 12x_{875} + 15x_{825} + 18x_{775} + 57x_{700} + 58x_{600}$
$i =$
$j = 7x_{975} + 8x_{925} + 9x_{875} + 10.5x_{825} + 12.5x_{775} + 30x_{700} + 48x_{600} + 51x_{500}$
$k =$
$l = 6x_{975} + 6.5x_{925} + 7x_{875} + 8x_{825} + 9x_{775} + 23x_{700} + 28.5x_{600} + 40x_{500} + 45x_{400}$
$m =$
$n = 5.5x_{975} + 6x_{925} + 7x_{875} + 8x_{825} + 8x_{775} + 19x_{700} + 21x_{600} + 25x_{500} + 33x_{400} + 36x_{300}$
$o =$
$p = 5.5x_{975} + 6x_{925} + 6.5x_{875} + 7x_{825} + 7x_{775} + 16x_{700} + 17.5x_{600} + 19.5x_{500} + 22.5x_{400} + 26.5x_{300} + 31x_{200}$
$q =$
$r = 5.5\,x_{975} + 6x_{925} + 6.5x_{875} + 7x_{825} + 7x_{775} + 15.5x_{700} + 16.5x_{600} + 17.5x_{500} + 18.5x_{400} + 18.5x_{300} + 21.5x_{200} + 20.5x_{100}$
$s =$
$t = 5.5x_{975} + 6x_{925} + 6.5x_{875} + 7x_{825} + 7x_{775} + 15x_{700} + 15.5x_{600} + 16.5x_{500} + 17x_{400} + 17.5x_{300} + 18x_{200} + 19x_{100} + 8x_0$

The central part of the radiation-curve has been reproduced on the annexed figure. For determining a, b, c, ... we have used the part included between $0^h\ 55^m$ and $1^h\ 37^m$, which was very carefully constructed on a larger scale. It deserves notice that the relative accuracy of the small ordinates (corresponding to few

minutes after totality) is nearly as great as that of the larger ones, because the galvanometer deflections from which they were calculated are all lying between 118 and 347 scale-divisions.

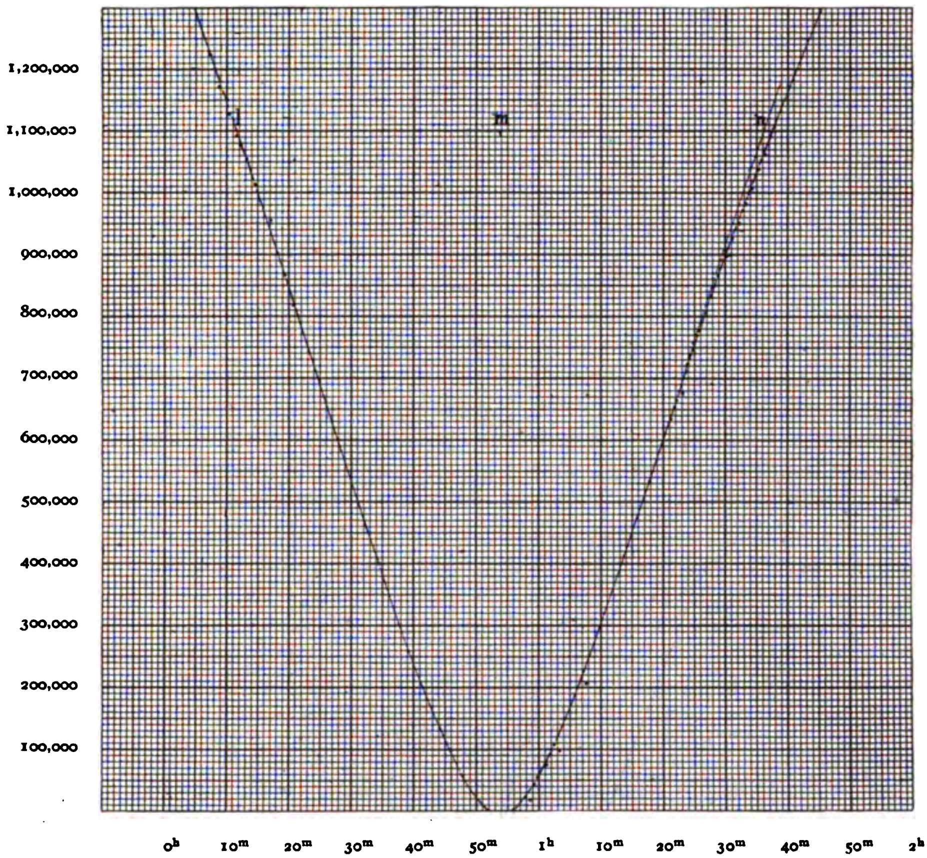


FIG. 1.—Central portion of the radiation-curve obtained during the solar eclipse of August 30, 1905.

Table II refers to this part of the radiation-curve. In the second column are given the ordinates of the curve at the epochs $0^h\ 55^m\ 40^s$ and every two minutes later; the unit corresponds to an intensity $=1000$. But this observational curve has to be corrected, owing to the circumstance that in the lapse of time considered the Sun's altitude has diminished. We may proceed as follows. Apart

TABLE II

Time	Ordinates of Radiation Curve	Ordinates of Corrected Radiation Curve	Increments	Time	Ordinates of Radiation Curve	Ordinates of Corrected Radiation Curve	Increments
$0^h\ 55^m\ 40^s$	0	0		$17^m\ 40^s$	532.0	535.0	$61.0=k$
57 40	20.1	20.1	$20.1=a$	19 40	594.0	597.0	$62.0=l$
59 40	52.5	52.5	$32.4=b$	21 40	655.0	659.0	$62.0=m$
1 1 40	91.0	91.0	$38.5=c$	23 40	717.0	721.0	$62.0=n$
3 40	136.5	136.5	$45.5=d$	25 40	776.0	783.0	$62.0=o$
5 40	187.0	187.0	$50.5=e$	27 40	834.5	844.5	$61.5=p$
7 40	240.0	241.0	$54.0=f$	29 40	891.5	905.5	$61.0=q$
9 40	296.0	297.0	$56.0=g$	31 40	947.0	966.0	$60.5=r$
11 40	354.0	355.0	$58.0=h$	33 40	1001.0	1026.0	$60.0=s$
13 40	412.0	414.0	$59.0=i$	35 40	1053.5	1085.5	$59.5=t$
15 40	472.0	474.0	$60.0=j$				

from a possible influence of sun-spots or faculæ, there is no reason why the eclipse-curve would not be symmetrical if the Sun's altitude (and the condition of our atmosphere) remained constant. Between 23^h and 1^h the variation of altitude is very small. Now, taking $0^h\ 53^m\ 50^s$ as the epoch of mid-eclipse, we draw a horizontal

TABLE III

RADIATION PER UNIT SURFACE OF THE CONCENTRIC ZONES OF THE SOLAR DISK

$x_{975}=0.1595$	$x_{500}=0.3843$
$x_{925}=0.2166$	$x_{400}=0.4153$
$x_{875}=0.2501$	$x_{300}=0.4278$
$x_{825}=0.3023$	$x_{200}=0.4240$
$x_{775}=0.3290$	$x_{100}=0.4380$
$x_{700}=0.3488$	$x_{0}=0.4388$
$x_{600}=0.3662$	

line through a point m corresponding to that epoch. The line cuts the descending branch of the curve in l; we make $mn=ml$ and thus find a point n of the hypothetical radiation-curve for constant altitude of the Sun. Acting in a similar way for a few more points, we get an idea of the magnitude of the smoothly increasing correction which is to be applied to the ordinates of the ascending branch. K. Ångström's measures of the intensity of the radiation for different altitudes of the Sun[1] have also been considered in determining the correction. The third column of Table II con-

[1] K. Ångström, "Intensité de la radiation solaire à différentes altitudes: Recherches faites à Ténériffe 1895 et 1896."

tains the ordinates of the corrected curve; in the fourth column are given their successive increments which, of course, are the values to be assigned to the absolute terms of our equations.

RESULTS

The solution of the equations leads to the numbers of Table III; the results are plotted in Fig. 2 on the plate. Through these points we have drawn a curve satisfying the condition that its curvature should gradually diminish; it shows us the law of variation of the

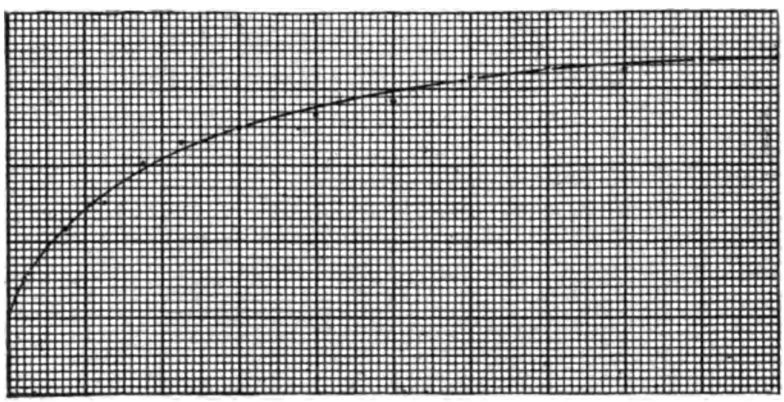


FIG. 2.—Radiating Power across the solar disk.

radiating power from the edge toward the center of the solar disk. Putting the ordinate at the center equal to 100, and expressing the other ordinates in the same unit, we get numbers comparable with the results obtained by other investigators.

The comparison with the spectro-photometric observations by H. C. Vogel,[1] and with the measurements of total radiation made with a radio-micrometer by W. E. Wilson[2] and with a thermopile by E. B. Frost,[3] is given in Table IV. We add in Table V the results of a spectro-bolometric investigation by Very,[4] as these

[1] *Ber. der Berl. Akad.*, 1877, p. 104.

[2] *Proc. Roy. Irish Acad.* [3], 2, 299, 1892.

[3] *Astronomische Nachrichten*, 130, 129, 1892.

[4] *Astrophysical Journal*, 16, 73, 1902.

numbers have been used by F. W. Very and by A. Schuster[1] in testing their explanations of the phenomenon.

According to Frost's measurements, the total radiation appears to diminish from the center to the limb in about the same proportion as the radiation of wave-length 650 $\mu\mu$, whereas my numbers show a decrease very similar to that exhibited by rays of wave-length 510 $\mu\mu$. At first sight the evidence is in favor of the results obtained by Frost, because the maximum of the curve representing the energy in the solar spectrum (or perhaps rather the "center of gravity" of the inclosed surface) lies closer to 650 $\mu\mu$ than to 510 $\mu\mu$. But this argument fails; for the measurements of Vogel and those of Frost are all disturbed alike by atmospheric diffusion. Had the

TABLE IV

Distance from Center of Disk	H. C. Vogel's Spectro-Photometric Measurements						Total Radiation		
	405–412 $\mu\mu$	440–446 $\mu\mu$	467–473 $\mu\mu$	510–515 $\mu\mu$	573–585 $\mu\mu$	658–666 $\mu\mu$	Receiver in Solar Image		Eclipse-Curve Julius
							Wilson	Frost	
0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
0.1	99.6	99.7	99.7	99.7	99.8	99.9	99.9	99.9	99.8
0.2	98.5	98.7	98.8	98.7	99.2	99.5	99.6	99.4	98.6
0.3	96.3	96.8	97.2	96.9	98.2	98.9	98.8	98.4	96.6
0.4	93.4	94.1	94.7	94.3	96.7	98.0	97.3	96.3	94.0
0.5	88.7	90.2	91.3	90.7	94.5	96.7	95.3	93.6	90.3
0.6	82.4	84.9	87.0	86.2	90.9	94.8	92.5	89.8	85.5
0.7	74.4	77.8	80.8	80.0	84.5	91.0	88.7	84.6	79.5
0.75	69.4	73.0	76.7	75.9	80.1	88.1			75.3
0.8	63.7	67.0	71.7	70.9	74.6	84.3	83.9	77.9	70.1
0.85	56.7	59.6	65.5	64.7	67.7	79.0			63.5
0.9	47.7	50.2	57.6	56.6	59.0	71.0	74.9	68.0	55.0
0.95	34.7	35.0	45.6	44.0	46.0	58.0		(60.5)	44.0
1.0	13.0	14.0	16.0	16.0	25.0	30.0	45.1		(24.0)

TABLE V

Distance from Center	F. W. Very's Spectro-Bolometric Measurements						
	416 $\mu\mu$	468 $\mu\mu$	550 $\mu\mu$	615 $\mu\mu$	781 $\mu\mu$	1010 $\mu\mu$	1500 $\mu\mu$
0.5	85.8	90.2	93.3	94.8	94.1	94.3	95.9
0.75	74.4	76.4	83.1	84.5	88.5	89.4	95.0
0.95	47.1	46.2	58.7	68.1	74.9	76.5	85.6

[1] *Astrophysical Journal*, 16, 320, 1902; 21, 258, 1905.

spectro-photometric observations been free from this influence, then the rate of decrease of the radiation from the center toward the limb would doubtless have been found quicker for all wave-lengths, and, very probably, the distribution for the region 650 $\mu\mu$ would have proved to agree better with my results than with the uncorrected values of Frost.

Wilson's measurements seem to have been affected by still other causes of error than atmospheric scattering, as his numbers are greater than those obtained by Frost, and do not harmonize as well as the latter's with the spectro-photometric series.

The observations of Very have given considerably greater ratios in the marginal regions than those of Vogel. Mr. Very himself points out the difference, and remarks that the bolometer has an advantage over the eye in the red where the heat is great; but I may suggest, on the other hand, that instrumental errors (reflection or scattering of light by prisms, lenses, tubes, etc.) are more easily discovered and corrected in spectro-photometric than in spectro-bolometric work.

It seems to me that observing an eclipse-curve by means of a very simple but sensitive actinometer, without lenses or mirrors, must yield results concerning the radiation of different parts of the solar disk which deserve more confidence than the values hitherto obtained in other ways. I wish to lay stress upon the advantages of our *method*, rather than on the reliability of the numbers secured at Burgos under not very favorable circumstances. In a clear sky the shape of the eclipse-curve will easily be found with very great accuracy.

The same method will also be applicable with radiations covering limited parts of the spectrum, if we only put suitable ray-filters before the opening of one of the diaphragms in the actinometer. It may even be possible, in a future eclipse, to use an arrangement which brings several ray-filters by turns before the opening; thus, when employing a quick galvanometer, one would be able to simultaneously determine, with one actinometer, the eclipse-curves for rays belonging to five or more regions of the spectrum, and the results would be independent of selective atmospheric scattering.

REMARKS ON THE HYPOTHESES USED FOR EXPLAINING THE DISTRIBUTION OF THE RADIATING POWER ON THE SOLAR DISK

The diminution of the intensity of radiation toward the limb is almost generally ascribed to absorption of the rays by the solar atmosphere,[1] and it is supposed that, in the absence of that atmosphere, the photosphere would show itself as an equally luminous disk. But then it appears to be impossible to find such values for the thickness of that atmosphere and for its coefficient of absorption as to give a law for the rate of diminution of brightness, consistent with observation. Very, for instance (*loc. cit.*), when attributing the effect to absorption only, arrives at the absurd result that the marginal measures indicate a more highly transmissive atmosphere than those measures nearer the center. He therefore suggests the existence of other influences which, combining with the absorbent process, would reconcile theory to observed facts. Diffraction by fine particles, columnar structure of the solar atmosphere, irregularity of the photospheric surface, are thus introduced.

Schuster (*loc. cit.*), on the other hand, is of opinion that the difficulty which has been felt in explaining the law of variation of intensity across the solar disk is easily removed by placing the absorbing layer sufficiently near the photosphere and taking account of the radiation which this layer, owing to its high temperature, must itself emit. He then really finds values for the absorption and the emission of that layer, harmonizing with the results of Very's and Wilson's[2] measurements, and also with the properties of the energy-curve of the spectrum of a black body at different temperatures. But, for all that, serious doubts as to the correctness of the premise and the conclusions must remain.

Indeed the calculations of Schuster as well as those of Very, Wilson, Langley, Pickering, and others, concerning the same subject, are based on the assumption that the light travels along straight lines through the solar gases, whereas everyone who has duly noticed A. Schmidt's ***Strahlenbrechung auf der Sonne*** will at the least have to admit that rays coming from the outer zones of the disk must have followed curved paths through the solar atmosphere. From this circumstance the said calculations lose their convincing power.

[1] J. Scheiner goes as far as to say: "Eine andere Deutung des Lichtabfalls ist nicht zulässig" (*Strahlung und Temperatur der Sonne*, p. 40).

[2] W. E. Wilson and A. A. Rambaut, *Proc. Roy. Irish Acad.* [3], **2**, 299–334, 1892.

And, besides, the fundamental idea that a considerable portion of the photospheric radiation should be absorbed by a thin atmosphere encounters a difficulty of greater importance still. This point, I think, has also first been raised by Schmidt. What becomes of the absorbed energy accumulating in the atmosphere? According to Schuster, e. g. (*loc. cit.*, p. 322), the atmosphere transmits largely one-third of the radiation emitted by the photosphere; so it stops almost two-thirds and only a small fraction of this absorbed energy leaves the Sun in the form of radiation emitted by the atmosphere itself. After all, more than half of the radiation coming from the photosphere is retained by the absorbing layer, and we cannot suppose it to go back to the interior without violating the second law of thermodynamics. As long as it has not been shown how the solar atmosphere may get rid of that immense quantity of energy continually supplied and never radiated, similar considerations will remain very unsatisfactory.

Our problem appears to be much less intricate when viewed from the standpoint taken by Schmidt,[1] though the mathematical treatment will not be easy. A uniformly luminous sphere surrounded by a concentric, perfectly transparent refracting envelope, will offer the aspect of a disk the brightness of which diminishes toward the limb. This has been stated approximately by Schmidt for the case of a homogeneous, sharply limited envelope. It is easily understood that a similar result must be obtained when a transparent atmosphere of gradually decreasing density and refractive power is assumed; but then, of course, the rate at which the luminosity varies on the disk will depend on the law of density-variation. We may proceed a little farther, and accept Schmidt's hypothesis that the incandescent core of the Sun is *not* a sphere with a sharp boundary, but a gaseous body the density and radiating power of which are smoothly diminishing along the radius. In this way, I think, we dispose of premises from which it seems possible to derive an explanation of the general aspect of the solar disk without involving such serious difficulties as were hitherto encountered.

UTRECHT,
February 1906.

[1] A. Schmidt, *Physikalishe Zeitschrift*, **4**, 282, 341, 453, 476; **5**, 67, 528. (1903 and 1904.)

THE SPECTRA OF SULPHUR DIOXIDE

By FRANCES LOWATER

I. THE ABSORPTION SPECTRUM

I. HISTORY

The absorption spectrum of sulphur dioxide was investigated in the ultraviolet region by W. A. Miller[1] in 1863. He inclosed the gas in a previously exhausted brass tube, two feet in length, the ends being closed by quartz plates. His source of radiation was the silver spark. He found that the silver spectrum was transmitted from scale-reading 96.5 to 110.5, at which point it was abruptly cut off. Estimated from a curve plotted from his maps, this range appears to be from λ 420 to 345 $\mu\mu$. He does not say at what pressure the gas was inclosed in the tube.

In 1883 Professors Liveing and Dewar[2] found that sulphur dioxide produced an absorption band "very marked between R (3179) and wave-length 2630, and a fainter absorption extending on the less refrangible side to O(3440), and on the other side to the end of the range photographed, wave-length 2300." They used as source of light the iron spark, and obtained the spectrum by means of a spectrometer having a single quartz prism and quartz lenses.

The present investigation was undertaken at the suggestion of Professor J. S. Ames, of Johns Hopkins University, and carried out at Bryn Mawr College.

II. APPARATUS AND METHOD

For the greater part of the work the gas was inclosed in a steel tube, 207 cm long, having its ends closed with quartz plates. It was provided with two pin valves for exhaustion of the tube and admission of the gas. The spectral apparatus was a quartz spectrograph of middle size by Fuess, used with a Rowland plane reflection grating having 14,438 lines to the inch.

[1] *Phil. Trans.*, **152**, II, 861–887, 1863.

[2] *Proc.. R. S*, **35**, 71–74, 1883.

In the region λ 690 to 390 $\mu\mu$ the carbon arc was used as source of light. In the region λ 410 to 210 $\mu\mu$ the source of light was the spark of an alloy of cadmium and zinc in proportions of their atomic weights. The beam was made parallel by a quartz lens before it entered the tube; on emergence it was brought, by another quartz lens, to a focus on the slit of the spectrograph. To obtain a continuous background with this spark, since no alternating current was available, the current from ten secondary cells was supplied to the primary of a ten-inch induction coil, and a capacity of 0.03 mfd. was placed across the terminals of the secondary, in parallel with the spark.

Before use the steel tube was thoroughly cleaned with hot potassium hydroxide and distilled water, and then thoroughly dried. The tube was exhausted by a water aspirator to about $1\frac{1}{2}$ cm pressure, filled with sulphur dioxide to a pressure greater than one atmosphere, and again exhausted; after this process had been repeated several times, the tube was filled with sulphur dioxide to the desired pressure. The sulphur dioxide was obtained from liquid sulphur dioxide; the high temperature of liquefaction (—10° C.) of this gas insures its purity from other gases except air, which may be present in the gas above the liquid. Before using any of the gas a considerable quantity was allowed to escape to insure that the following supply of gas should be free from air. Before admission into the tube, the sulphur dioxide was passed through a tube containing phosphorus pentoxide to insure its dryness.

The photographic plates used were Seed's No. 27 Gilt Edge. An exposure of two hours was given for the absorption spectrum in every case. A comparison spectrum was photographed on the same plate as the absorption spectrum immediately above or below the latter.

Standard wave-lengths were obtained from the lines of *Cd*, *Zn*, *Pb*, and *Fe*, which were transmitted in sufficient numbers in the absorption spectrum, the *Pb* and *Fe* being present as impurities; by this means errors were avoided that might arise from disturbance of the apparatus in changing from the arrangement for the absorption spectrum to that for the comparison or another standard spectrum.

The absorption spectrum of sulphur dioxide in the violet and ultra-violet regions was found for pressures of three atmospheres, two atmospheres, and one atmosphere, $1\frac{1}{2}$ cm, 0.45 cm, and 0.13 cm. The wave-lengths were determined by measurements made on the photographic plates in the usual way. The dividing engine used for this purpose was one by Gaertner, on which readings could be made to 0.0001 mm; that is, to a greater accuracy than settings could be made on the bands. The reduction factor was roughly 32 tenth-meters to 1 mm.

III. RESULTS

In the region λ 690 to 390 $\mu\mu$ no absorption bands are found. In the region λ 410 to 210 $\mu\mu$ the photographs show that the absorption spectrum, except at very low pressures of the gas, consists of one very wide band and a number of comparatively narrow bands of different widths and intensities. Tables I and II give the wave-lengths and intensities of the bands. The intensities are estimated by eye from the photographic plates; the scale is from 10 to $\frac{1}{2}$, 10 being the maximum and applied to bands at whose center of gravity none of the continuous background is transmitted. In many cases it is difficult to obtain accurate values of the wave-lengths; in some cases this is due to the width of the band—e. g., 3, 8, or 11 tenth-meters, while in other cases it is due to the presence of a metal line which falls within the absorption band and is strong enough to be transmitted when the continuous background is absorbed. This limitation in accuracy is apparent on comparing the readings for the same line as given in parallel columns in the tables which follow.

A tube filled with oxygen at one atmosphere's pressure and sulphur dioxide at one atmosphere's pressure gave the same spectrum as the tube filled with sulphur dioxide only at one atmosphere's pressure.

In the tables, s. denotes sharp, b. broad, n. narrow, h. hazy, i.d. ill defined, and v. very.

TABLE I

ABSORPTION SPECTRUM OF SULPHUR DIOXIDE AT DIFFERENT ATMOSPHERIC PRESSURES

λ for 3 Atmos. Pressure	Intensity and Character	λ for 2 Atmos. Pressure	Intensity and Character	λ for 1 Atmos. Pressure	Intensity and Character
3881.7	9b.	3881.5	6	3881.8	1
3878.4	2s.	3878.7	3	3878.8	1n.
3828.3	10b.	3828.5	6	3828.5	2
		3825.3	3	3825.2	1n.
3776.3	3	3776.3	2	3776.4	½
3750.6	10b.	3751.1	8	3751.0	3b.
		3747.0	5s.	3747.0	2
3701.9	10v.b.	3701.7	10b.	3701.3	5s.
				3698.9	2n.
3657.4	2s.	3657.5	3n.	3657.6	1
3654.4	1	3654.4	3	3654.1	1
3650.6	1s.	3650.6	3n.	3650.7	1
3635.4	4b.	3635.4	4b.	3636.2	1b.
		3628.4	1		
		3623.5	2		
3593.9	4b.	3594.2	4v.b.	3594.2	1
3579.0	8b.	3579.1	5b.	3579.2	2
3532.8	9b.	3532.4	5b.	3532.5	1
		3529.6	3n.	3529.6	½
		3522.2	1		
		3512.3	½		
3509	f.b.	3510.1	1		
		3507.2	1		
3504	f.n.	3503.5	½		
3494.2	1	3494.1	1		
3490.1	1	3490.2	1		
3486.8	1	3486.2	½		
3474.7	1s.	3474.8	½		
3442.6	4b.	3443.2	4b.	3443.2	1
3434.1	1	3435.1	2		
3431.7	1	3432.2	2		
3423.9	2				
3422.6	3	3422.1	1		
3421.2	5	3421.3	2		
3418.7	5	3418.7	2		
3416.8	3	3417.1	2		
3414.3	2				
3412.4	2				
		3406.9	½		
3401.2	2				
3399.8	2				
3398.4	5	3398.3	1i.d.		
		3395.9	5i.d.		
3394.8	8				
		3393.9	4i.d.		
3392.5	6	3392.0	4i.d.		
		3389.3	4		
3386.7	7	3387.0	5		
3380	beginning of wide band	3384.7	4		
		3378.0	8		

TABLE I—*Continued*

λ for 3 Atmos. Pressure	Intensity and Character	λ for 2 Atmos. Pressure	Intensity and Character	λ for 1 Atmos. Pressure	Intensity and Character
		3375.9	9		
		3372.0	9	3372.1	2s.
		3365.9	9	3364.1	4s.
		3358.4	9	3358.7	8s.
		3351	beginning of wide band	3350.8	4s.
				3338.4	7
				3333.4	10
				3330	beginning of wide band

TABLE II

ABSORPTION SPECTRUM OF SULPHUR DIOXIDE AT LOW PRESSURES.

Length of Column of Gas = 207 cm				Length of Column of Gas = 20 cm	
λ for 1½cm. pressure	Intensity and Character	λ for 0.13 cm. Pressure	Intensity and Character	λ for 1.35 cm. Pressure	Intensity and Character
3226.2	2				
3211.4	1				
3207.6	1				
3203.4	1				
3198.3	3				
3195.4	4				
3190.3	1				
3187.1	1			3178.6	f.
3180.6	9	3180.7	2		
3171.5	8 n.h.				
3166.2	8 n.h.				
3157.5	10 h.				
3152.7	10 h.	3151.9	2		
		3149.8	½s.	3150.0	½
		3147.8	½s.		
3146.6	10 h.	3145.3	½		
		3143.1	½s.		
		3137.7	½		
3134	beginning of wide band	3131.0	5n.		
		3128.7	2s.	3129.3	1
		3125.7	2s.	3124.6	1
		3120.3	4n.		
		3111.3	5s.		
		3105.8	7	3104.7	6
		3101.4	4s.		
				3093.2	1s.
				3089.7	1s.
		3086.0	10	3086.2	8s.
				3084.2	2s.
				3082.4	2s.

TABLE II.—*Continued*

Length of Column of Gas = 207 cm				Length of Column of Gas = 20 cm	
λ for 1½ cm Pressure	Intensity and Character	λ for 0.13 cm Pressure	Intensity and Character	λ for 1.35 cm Pressure	Intensity and Character
		3064.9	10	3063.4	9
		3043.9	10	3042.6	9
		3022.6	10	3021.7	10
		3003.6	10 i.d.	3001.4	10
		2988	10 i.d.		
				2981.5	10
		2978	10 i.d.		
		2968	beginning of wide band	2962.0	10
				2943.0	10
				2927.	beginning of wide band
		2715.3	end of wide band		
		2701.5	9	2700.3	end of wide band
		2693.5	7	2692.3	9 i.d.
		2684.8	9	2683.7	10
		2676.7	7	2676.3	10
		2669.5	9	2668.6	10
		2660.1	8	2659.4	10
		2654.9	7	2653.2	9
		2653.3	7		
		2647.1	8	2646.6	9
		2643.0	7	2642.9	8
		2638.0	8	2637.3	9
		2633.0	7n.	2632.7	8
		2627.5	5	2627.1	7
		2623.1	5		
		2620.9	5	2621.2	8
		2616.9	5		
		2615.4	5		
		2613.7	7s.	2613.8	7
		2611.4	4		
		2596.8	5	2596.2	5
		2591.4	4	2590.8	3
		2585.2	3		
				2583.5	4
		2582.7	3		
		2512.2	3		
		2495.9	4	2496.2	2
		2478.1	3	2477.6	1
		2471.6	3	2471.4	1
2467	end of wide band				
		2464.3	2		
2456.	9 i.d.	2454.1	7	2454.5	2
		2448.3	6	2447.9	1

TABLE II.—*Continued*

LENGTH OF COLUMN OF GAS=207 CM				LENGTH OF COLUMN OF GAS=20 CM	
λ for 1½ cm Pressure	Intensity and Character	λ for 0.13 cm Pressure	Intensity and Character	λ for 1.35 cm Pressure	Intensity and Character
2439	9 v.i.d.				
		2433.1	3		
2415.5	9 i.d.				
2401	9 i.d.	2401.0	2		
2397	8 i.d.	2397.5	1		
2379	8 i.d.				
2372	8 i.d.				
2367	8 i.d.				
2349	8 i.d.				
2345.5	8 i.d.				
2339	6 i.d.				
2327.5	7 i.d.				
2324	7 i.d.				
		2318.4	5		
		2308.7	6n.		
2304	6 i.d.	2303.2	8		
2297	7 i.d.	2298.0	9	2298.4	6
		2290.5	4		
2290	beginning of second wide band				
		2277.5	10	2278.4	9n.
		2269.2	6		
				2258.6	10n.
		2250.4	beginning of second wide band	2251.0	beginning of second wide band

IV. DISCUSSION

The following changes in the absorption spectrum with reduction of pressure may be noticed; they are evident from the plates.

1. As the pressure is reduced from three atmospheres to two, and from two to one, the bands become narrower and fainter, and the less refracted end of the very wide continuous band retreats toward the shorter wave-lengths, this part of the continuous absorption being replaced by narrow bands.

2. At the low pressures—namely 1½, 0.45, 0.13 cm—the above changes are more marked; the narrow bands existing at one or more atmosphere's pressure have entirely disappeared; the wide continuous band has retreated not only from the longer wave-lengths but also from the shorter; and there is very little absorption beween

λ 257 and 230 $\mu\mu$. At the lowest pressure used, a pressure somewhat less than 0.13 cm, the wide continuous band is entirely broken up into narrow bands.

The shortest wave-length photographed was 210 $\mu\mu$; from this wave-length to 230 $\mu\mu$ the absorption decreases with the pressure, but is ill-defined, probably on account of the weakness of the continuous background.

A set of photographs has been taken of the absorption by a column of gas 20 cm in length with the gas at a pressure of 1.35 cm. Since the product

$$\text{(pressure of gas)} \times \text{(length of column of gas)} = 207 \times 0.13 = 20 \times 1.35 ,$$

the number of molecules which the beam meets in traversing a column of gas 207 cm long at a pressure of 0.13 cm is the same as it meets in traversing a column 20 cm long at a pressure of 1.35 cm. Since the numbers of molecules met in the two cases is the same we might expect the absorption to be the same, provided the physical condition of the molecules is the same. It was found that the absorption spectrum obtained from the column of gas 20 cm long at a pressure of 1.35 cm, corresponds very closely with that obtained from the column of gas 207 cm long at a pressure of 0.03 cm, but certain bands in the former are shifted toward the more refracted end of the spectrum; this is obvious from the photograph.

Photographs with this short column at pressures of 1.0 and 0.53 cm show the wide continuous band being gradually broken up into narrow bands. It is intended to extend this part of the work at the earliest opportunity.

Any mathematical relation between the wave-lengths of the bands or their reciprocals is obscure, particularly at the pressures of one or more atmospheres. The reciprocals of the wave-lengths with their differences are shown in Table III.

The differences of the frequencies suggest that the bands are arranged in groups with roughly equal differences between the first bands of successive groups; or we may regard the bands as arranged in series with roughly equal differences between the reciprocals of successive members of a series. Where the members of a series are scattered in Table III, they have been collected at the foot of

TABLE III

Wave-Lengths and Their Reciprocals at Pressure of 2 Atmospheres

λ	$\frac{1}{\lambda} \times 10^7$	Successive Diff'r'nces	Group Differ.	λ	$\frac{1}{\lambda} \times 10^7$	Successive Diff'r'nces	Group Diff'r'nces
3881.5	2576.3			3486.2	2868.5		
		1.9				9.4	
3878.7	2578.2		35.7	3474.7	2877.9		
		33.8				26.4	26.4
3828.5	2612.0			3443.2	2904.3		
		36.0	36.0			6.8	
3776.4	2648.0			3435.1	2911.1		
		17.8				2.5	
3751.2	2665.8		20.7	3432.2	2913.6		
		2.9				8.6	
3747.2	2668.7			3422.1	2922.2		22.2
		32.9	32.9			0.7	
3701.5	2701.6			3421.3	2922.9		
		32.5	32.5			2.2	
3657.5	2734.1			3418.7	2925.1		
		2.3				1.4	
3654.4	2736.4			3417.1	2926.5		
		2.9				8.7	
3650.6	2739.3			3406.9	2935.2		
		11.4	25.7			8.4	
3635.4	2750.7			3398.3	2943.6		
		5.3				1.1	
3628.4	2756.0			3395.9	2944.7		
		3.8				1.8	26.0
3623.5	2759.8			3393.9	2946.5		
		22.6				1.7	
3594.0	2782.4		34.2	3392.0	2948.2		
		11.6				2.3	
3579.1	2794.0			3389.3	2950.5		
		36.9	36.9			2.0	
3532.4	2830.9			3387.0	2952.5		
		2.4				2.0	
3529.5	2833.3			3384.7	2954.5		
		5.8				5.8	
3522.2	2839.1			3378.0	2960.3		
		8.0				1.9	
3512.3	2847.1		23.4	3375.9	2962.2		25.1
		1.8				3.4	
3510.1	2848.9			3372.0	2965.6		
		2.4				5.4	
3507.2	2851.3			3365.9	2971.0		
		3.0				6.6	
3503.5	2854.3			3358.4	2977.6		
		7.7					
3494.0	2862.0						
		3.2	23.6				
3490.2	2865.2						
		3.3 (9.4)					

SERIES OF BANDS

$\frac{1}{\lambda}\times10^7$	Difference	$\frac{1}{\lambda}\times10^7$	Difference	$\frac{1}{\lambda}\times10^7$	Difference
I		II		III	
				2830.9	
		2847.1			23.4
2851.3			21.4	2854.3	
	26.6	2868.5			
2877.9			45.1 $=22.5\times2$		68.6 $=22.9\times3$
	26.4				
2904.3					
	22.2	2913.6			
2926.5			21.6	2922.9	
	26.0	2935.2			23.6
2952.5			19.3	2946.5	
	25.1	2954.5			24.5
2977.6				2971.0	

AT PRESSURE OF 1½ CM

λ	$\frac{1}{\lambda}\times10^7$	Successive Diff'r'nces	Group Diff'r'nces	λ	$\frac{1}{\lambda}\times10^7$	Successive Diff'r'nces	Group Diff'r'nces
3226.2	3099.6			2456	4071.5		
		14.3				28.5	28.5
3211.4	3113.9		18.0	2439	4100		
		3.7				40	40
3207.6	3117.6			2415.5	4140		
		4.1				25	
3203.4	3121.7			2401	4165		32
		5.0				7	
3198.3	3126.7			2397	4172		
		2.8	20.0			31.5	31.5
3195.4	3129.5			2379	4203.5		
		5.0				12.5	
3190.3	3134.5			2372	4216		23.5
		3.1				11	
3187.1	3137.6			2367	4225		
		6.5				32	32
3180.6	3144.1			2349	4257		
		9.0	20.8			6.5	
3171.5	3153.1			2345.5	4263.5		18
		5.3				11.5	
3166.2	3158.4			2339	4275		
		8.7				21.5	
3157.5	3167.1			2327.5	4296.5		28
		4.8	19.6			6.5	
3152.7	3171.9			2324	4303		
		6.1				37	37
3146.6	3178.0			2304	4340		
						14	
				2297	4354		

SERIES OF BANDS

$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference
I		II		III	
3099.6		3113.9		3117.6	
	22.1		20.6		20.0
3121.7		3134.5		3137.6	
	22.4		18.6		20.8
3144.1		3153.1		3158.4	
	23.0		18.8		19.6
3167.1		3171.9		3178.0	

AT PRESSURE OF 0.13 CM

λ	$\frac{1}{\lambda}\times 10^7$	Successive Differences	Group Differences	λ	$\frac{1}{\lambda}\times 10^7$	Successive Differences	Group Differences
3180.7	3144.0			3003.6	3329.6		
		28.7				17.3	17.3
3151.9	3172.7			2988	3343.6		
		2.1					
3149.8	3174.8						
		2.0					
3147.8	3176.8						
		2.5					
3145.3	3179.3						
		2.4					
3143.1	3181.7						
		5.3		2701.5	3701.6		
3137.7	3187.0		20.0			11.0	
		6.9		2693.5	3712.6		
3131.0	3193.9					12.1	
		2.3		2684.8	3724.7		23.3
3128.7	3196.2					11.2	
		3.1		2676.7	3735.9		
3125.7	3199.3					11.1	
		5.5		2669.5	3746.0		21.3
3120.3	3204.8		20.5			13.2	
		9.3		2660.1	3759.2		
3111.3	3214.1					7.4	
		5.7		2654.9	3766.6		
3105.8	3219.8					2.3	
		4.6		2653.3	3768.9		24.4
3101.4	3224.4		20.6			8.8	
		16.0		2647.1	3777.7		
3086.0	3240.4					5.9	
		22.3	22.3	2643.0	3783.6		
3064.9	3262.7					7.2	
		22.6	22.6	2638.0	3790.8		
3043.9	3285.3					7.1	22.3
		23.1	23.1	2633.0	3797.9		
3022.6	3308.4					8.0	
		20.9	20.9	2627.5	3805.9		

AT PRESSURE OF 0.13 CM (CONTINUED)

λ	$\frac{1}{\lambda}\times 10^7$	Successive Differ-ences	Group Differ-ences	λ	$\frac{1}{\lambda}\times 10^7$	Successive Differ-ences	Group Differ-ences
		6.4		2464.3	4057.9		
2623.1	3812.3					16.9	
		3.2		2454.1	4074.8		26.6
2620.9	3815.5					9.7	
		5.8	20.1	2448.3	4084.5		
2616.9	3821.3					25.5	25.5
		2.2		2433.1	4110.0		
2615.4	3823.5					54.9	2×27.5
		2.5		2401.0	4164.9		
2613.7	3826.0					6.1	
		3.4		2397.5	4171.0		
2611.4	3829.4						
		21.5	21.5	2318.4	4313.3		
2596.8	3850.9					18.1	
		8.0		2308.7	4331.4		28.5
2591.4	3858.9					10.4	
		9.3	21.0	2303.2	4341.8		
2585.2	3868.2					9.8	
		3.7		2298.0	4351.6		
2582.7	3871.9					25.3	25.3
				2290.5	4376.9		
2512.2	3980.6					13.9	
		26.0	26.0	2277.5	4390.8		29.9
2495.9	4006.6					16.0	
		28.8	28.8	2269.2	4406.8		
2478.1	4035.4						
		10.6					
2471.6	4046.0		22.5				
		11.9					

SERIES OF BANDS

$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference
I		II		III	
3701.6					
	23.1	3712.6			
3724.7			23.3		
	21.3	3735.9			
3746.0			23.3		
	22.9	3759.2			
3768.9			24.4	3777.7	
	21.9	3783.6			20.2
3790.8			22.3	3797.9	
	21.5	3805.9			23.4
3812.3			20.1	3821.3	
		3826.0			
			24.9		
		3850.9			
			21.0		
		3871.9			

LENGTH OF COLUMN OF GAS = 20 CM
AT PRESSURE OF 1.35 CM

λ	$\frac{1}{\lambda}\times 10^7$	Successive Differences	Group Differences	λ	$\frac{1}{\lambda}\times 10^7$	Successive Differences	Group Differences
3178.6	3146.4			2692.3	3714.3		
		28.2	28.2			11.9	22.2
3150.0	3174.6			2683.7	3726.2		
		21.0	21.0			10.3	
3129.3	3195.6			2676.3	3736.5		
		4.8				10.8	23.7
3124.6	3200.4			2668.6	3747.3		
		20.5	20.5			12.9	
3104.7	3220.9			2659.4	3760.2		
		12.0	21.4			8.8	23.5
3093.2	3232.9			2653.2	3769.0		
		3.7				9.4	
3089.7	3236.6			2646.6	3778.4		
		3.6				5.3	
3086.2	3240.2			2642.9	3783.7		
		2.1				8.1	22.8
3084.2	3242.3			2637.3	3791.8		
		1.9	22.0			6.6	
3082.4	3244.2			2632.7	3798.4		
		20.1				8.1	
3063.4	3264.3			2627.1	3806.5		
		22.4	22.4			8.5	19.3
3042.6	3286.7			2621.2	3815.0		
		22.7	22.7			10.8	
3021.7	3309.4			2613.8	3825.8		
		22.4	22.4			26.0	26.0
3001.4	3331.8			2596.2	3851.8		
		22.2	22.2			8.0	18.9
2981.5	3354.0			2590.8	3859.8		
		22.1	22.1			10.9	
2962.0	3376.1			2583.5	3870.7		
		21.8	21.8				
2943.0	3397.9			2496.2	4006.1		
						30.1	
				2477.6	4036.2		
						10.1	
				2471.4	4046.3		
						27.9	
				2454.5	4074.2		
						10.9	
				2447.9	4085.1		
				2298.4	4350.9		
						38.1	
				2278.4	4389.0		
						38.5	
				2258.6	4427.5		

SERIES OF BANDS

$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference
3714.3					
	22.2	3726.2			
3736.5			21.1		
	23.7	3747.3			
3760.2			21.7		
	23.5	3769.0			
3783.7			22.8	3778.4	
	22.8	3791.8			20.0
3806.5			23.2	3798.4	
		3815.0			27.4
				3825.8	
					26.0
				3851.8	

the subdivisions of that table. These differences change gradually with the wave-length; they decrease from the longer to the shorter wave-lengths until the wide band is reached, then increase on the other side of it. The direction of this change corresponds with the change in absorption as the pressure is reduced; the bands decrease in intensity and eventually disappear first in the longer wave-lengths on the less refracted side of the wide band, and at the same time in the shorter wave-lengths on the more refracted side.

Region	Mean Difference in Frequency
380 to 350 $\mu\mu$	34
350 to 330 $\mu\mu$	25
330 to 313 $\mu\mu$	20
318 to 298 $\mu\mu$	21
272 to 258 $\mu\mu$	22
250 to 230 $\mu\mu$	30

Photographs taken with the column of gas 20 cm long show a rather more regular structure of bands; also some groups or series.

These groups of bands or series, combined with the breaking up of the wide continuous band into a considerable number of narrow bands as the pressure is reduced, suggest the possibility that all these bands may eventually be found to consist of very narrow bands or lines.

V. CONCLUSION

Although the series are at least in some cases incomplete and the differences in the wave-numbers are not equal, yet the near approach of these differences to equality with one another cannot be ignored. Thus this spectrum appears to consist of series of bands which follow approximately a law of equal differences. With the gas under conditions of pressure and temperature other than those tried, it may be found that its spectrum consists of quite definite series which follow closely a law of equal differences between the wave-numbers.

II. THE BAND EMISSION SPECTRUM OF SULPHUR DIOXIDE

I. APPARATUS AND METHOD

The usual conditions necessary to maintain the gas as a compound while under the electrical discharge were obtained as follows: The feeble electrical excitation was obtained from the secondary of a ten-inch induction coil, the primary of which was supplied with the current from three storage cells; the terminals of the secondary were placed too far apart for a spark to pass between them, and the vibrator was adjusted loosely. The spectrum tube had outside electrodes of lead foil with a layer of mica between them and the glass walls. As a further aid in preventing the decomposition of the gas, electrolytically prepared oxygen was mixed with the sulphur dioxide in the spectrum tube.

The sulphur dioxide was obtained from liquid sulphur dioxide which had been redistilled. The gas was dried by passing it through a bulb closely packed with phosphorus pentoxide; it was then admitted to the apparatus through a barometer column. Interposed between the barometer column and the spectrum tube were two U-tubes, one containing gold foil to absorb mercury vapor, and the other packed with phosphorus pentoxide to insure more perfect dryness of the gas. Similar tubes were interposed between the other end of the spectrum tube and the McLeod gauge and vacuum pump. All connections of the apparatus from the barometer column to the far side of the pump were either blown glass joints or mercury seal joints.

The spectrum tube was cleaned by soaking it in chromic acid

for ten or twelve hours, then washing it with distilled water, then with nitric acid, and again with distilled water; it was then dried by keeping it at a temperature of from 110° to 120° C. for eight or ten hours, meanwhile drawing a current of dry air through it. No bands from carbon compounds nor any of the strong hydrogen lines were ever seen or found on a photographic plate. The tube was exhausted, sparked, filled with oxygen, re-exhausted, and the process repeated until no air lines appeared.

The oxygen was prepared electrolytically from a 20 per cent. solution of crystallized phosphoric acid and dried by passing it through two bulbs loosely packed with phosphorus pentoxide and then through a U-tube closely packed with the same and plugs of glass wool. The line spectrum of oxygen was photographed in the region between λ 327 and 432 $\mu\mu$. It is well known that oxygen has no bands in this region.

As a standard spectrum that of the iron spark was used with the wave-lengths published by Kayser in his *Handbuch der Spectroscopie*, Vol. I.

The spectral apparatus was a Rowland concave grating mounted on the Rowland plan; it has a radius of 180 cm (5 ft. 11 in.), 15,028 lines to the inch, and a ruled surface 52 mm ($2\frac{7}{16}$ in.) wide. The wave-lengths were determined in the usual way by measurements made by means of the dividing engine mentioned above; the reduction factor was approximately 9.3 tenth-meters to 1 mm.

II. RESULTS

The chief difficulty in obtaining the spectrum of the compound lay in the extreme faintness of the light and the long exposures necessary. With the light from the capillary used "end-on" and a slit-width of about 0.05 mm, a continuous exposure of 45 hours gave only weak bands in the ultra-violet and very weak bands in the violet; the lines of the bands were too coarse for measurement. The wave-lengths of the heads of the bands obtained from this photograph are given in Table IV. A continuous exposure of 69 hours with a slit-width of 0.035 mm approximately gave bands too faint for measurement. A continuous exposure of 91 hours with a slit-width of 0.018 mm approximately was spoiled by ham-

mering in another room in the building. For the spectrum for which measurements are given the pressure of sulphur dioxide was 0.27 cm, and the pressure of oxygen 0.28 cm making a total pressure of 0.55 cm at the beginning of the exposure. During exposure, oxygen and sulphur dioxide were added to try to keep the condition of the tube constant; the total pressure at the end of the exposure was 0.45 cm. Hitherto no attempt has been made

TABLE IV

BAND EMISSION SPECTRUM OF SULPHUR DIOXIDE

WAVE-LENGTHS OF THE HEADS OF THE BANDS AND THEIR RECIPROCALS

	λ	Intensity and Character	$\frac{1}{\lambda} \times 10^7$	Successive Differences
1.	3271.4	4	3056.8	
2.	3383.7	5	2955.3	101.5
3.	3428.0	4	2917.1	38.2
4.	3502.3	5	2855.2	61.9
5.	3548.7	5	2817.9	37.3
6.	3628.0	4	2756.3	61.6
7.	3675.9	5	2720.4	35.9
8.	3726.5	2	2683.5	36.9
9.	3761.5	f	2658.5	25.0
10.	3811.3	5	2623.8	34.7
11.	3862.7	2	2588.8	35.0
12.	3954.6	5 h.	2528.7	60.1
13.	4007.6	4 h.	2495.2	33.5
14.	4040.6	3 v.i.d.	2474.9	20.3
15.	4107.3	2 i.d.	2434.7	40.2
16.	4145.5	2	2412.3	22.4
17.	4153.4	2	2407.7	4.6
18.	4163.0	3 h.	2402.1	5.6

TABLE V

SERIES OF BANDS

$\frac{1}{\lambda} \times 10^7$	Difference	$\frac{1}{\lambda} \times 10^7$	Difference	$\frac{1}{\lambda} \times 10^7$	Difference
I		II		III	
1) 3056.8					
	101.5	3) 2917.1			
2) 2955.3			99.2		
	100.1	5) 2817.9			
4) 2855.2			97.5		
	98.9	7) 2720.4			
6) 2756.3			96.6	8) 2683.5	
	97.8	10) 2623.8			94.7
9) 2658.5			95.1	11) 2588.8	
		12) 2528.7			93.6
			94.0	13) 2495.2	
		15) 2434.7			93.1
				18) 2402.1	

to photograph this spectrum in regions of greater wave-length where longer exposures would be necessary.

The spectrum thus obtained consists of bands with distinct heads turned toward the ultra-violet, and is thus characteristically different from the "band" or compound line spectrum of elementary sulphur obtained by Eder and Valenta, and published in their paper, "Die Spectren des Schwefels," 1898.

The reciprocals of the wave-lengths (Table IV) show that the bands can be arranged in three series with decreasing difference of wave-numbers (Table V). The series will be seen to follow roughly Deslandres' law. These series are doubtless incomplete, as the range photographed covers only 105 $\mu\mu$.

My investigation of the spectrum of sulphur dioxide was begun originally at the suggestion of Professor A. Stanley Mackenzie with the purpose of comparing it with that of sulphur as determined by Runge and Paschen and by Eder and Valenta. Owing to various causes, this plan was not carried into effect, and the research as described in the preceding pages was proposed by Professor J. S. Ames, to whom I desire to express my indebtedness and my gratitude for his kindness in directing my work and for his invaluable suggestions in the carrying out of this investigation. I wish at the same time to express my thanks to Dr. H. W. Springsteen, asso-

ciate in physics, for the generosity with which he has provided me with the laboratory apparatus needed for this piece of work; also to Dr. W. B. Huff, professor of physics, and to Dr. E. P. Kohler, professor of chemistry, for frequent help and encouragement, particularly during the early part of my work.

BRYN MAWR COLLEGE,
March 31, 1906.

Minor Contributions and Notes

REMARKS ON MR. C. L. POOR'S PAPERS ON THE FIGURE OF THE SUN

In the second and fifth numbers of the last volume of this *Journal*[1] Mr. C. L. Poor has published some investigations as to the figure of the Sun, in which he believes that he has proved the existence of periodic changes. I am led to discuss briefly his research here, inasmuch as he has included in his considerations my memoir on the Göttingen heliometer measurements of the Sun's diameter, and has sought to show that it contains certain oversights. After being busied for years with this subject, I am for my part by no means convinced by the presentation of Mr. Poor; but I here wish to show by a few examples that his investigations are not quite to the point. I shall give elsewhere a full discussion of them.

The results from the earlier photographic plates surely did not possess the precision necessary for proving such oscillations of the ratio between the polar and equatorial diameter; for, according to our heliometer measurements, it is quite beyond the possibility that these variations, if present at all, can exceed $0\overset{''}{.}1$ by an appreciable amount; but our measurements in the year 1894 furnish for the more recent photographs just the proof that the oscillations adduced by Mr. Poor are not present, as is shown by the following summary for P.−E.

Photographic Measures	Heliometer Measures		
Poor	Schur	Ambronn	Mean Schur and Ambronn
1894 July 10 $-0\overset{''}{.}72 \pm 0\overset{''}{.}24$ July 17 $+0.36 \pm 0.23$	July 6 $+0\overset{''}{.}15$ July 24 -0.25	July 7 $-0\overset{''}{.}25$ July 25 -0.04	$-0\overset{''}{.}05$ -0.14

I would remark as to the errors found by Mr. Poor in my memoir that only the one adduced for the year 1898 should be actually regarded as such. It should actually there read $+0\overset{''}{.}11$ instead of $-0\overset{''}{.}11$, and the slip is due to the fact that in Schur's summaries, not all of which were subsequently computed by me (since they had been made out with the greatest of care), an error was evidently left in the transcription of a number. The three other errors, however, are not present in the table on

[1] **22**, 103–114, 305–317, 1905.

page 44 of my paper. The number for 1891 is there given perfectly correctly, but in the copy of the special summary of the deviations on page 108 there is a typographical error. For September 10/11 we should read under P.—E. $-0''.64$ instead of $-0''.04$, as might at once have been seen from the original data on page 74. The figure for the year 1896 is entirely correct in my table on page 44, on which alone the discussion was based; the figure for Schur's observations in 1900 includes, however, the wholly isolated measure in 1901, and is then entirely correct, which fact Mr. Poor seems to have overlooked.

There therefore remains, as affecting the whole consideration, solely the error for 1894, and it is easy to see that this is without any signification as to the result, from the circumstance that this high positive value owes its origin to an entirely accidental accumulation of observations in May and June, and the single observation of December 7, designated by Schur himself as very poor. (See page 84 of my paper.) It is not at all confirmed by the inclusive observations of Schur and myself in May and June 1898.

Although the derivation of variations of the solar diameter in polar and equatorial directions is thereby made very improbable, I must nevertheless here further state that later Mr. Poor still includes in his discussion the observations for the years 1890 and 1891. These should in this case certainly be excluded, because we can *not* exclude from these measurements any physiological error which might be present affecting the two directions unequally. If we take this into account, not only are the conclusions based on the curves upset, but also the tables on pages 310 and 313 take an entirely different form. The mean errors of a year's average for the value of P.—E. come out as about $+0''.07$ and $+0''.06$ for Schur and Ambronn, respectively, if we assume in round numbers sixteen observations in the year. These errors are, however, such that almost all the year's averages for P.—E. fall between these limits during the years 1892–1902, which *alone* ought to be considered. Hence in my view there is no occasion at all, on the basis of our heliometer measurements, to assume such periodic variations as Mr. Poor believes he has found. It would have been very interesting to me to have been able to establish such a periodicity from my discussion of the Göttingen heliometer observations, but the most thorough investigation of the large amount of data collected by us has convinced me that this furnishes no justification for such a periodicity.

L. AMBRONN.

GÖTTINGEN,
February 25, 1906.

NOTE ON THE ULTRA-VIOLET RADIATION OF SUN-SPOTS AND FACULÆ

In connection with the investigations of Messrs. Hale, Adams, and Abbot on the radiation of sun-spots[1] we beg to communicate a few observations on the ultra-violet radiation of sun-spots and faculæ. These are based on the solar plates taken with light of wave-length 320 $\mu\mu$, upon which we report fully elsewhere in this number. We were struck at the beginning by the fact that the umbræ of the larger spots on these plates exhibit strong contrast to the surroundings. Measurements were made in the following manner. A setting was made under a Hartmann photometer on the opacity of the spot upon a solar image obtained with the full aperture of the instrument, and then upon the image taken with a diaphragm $\frac{1}{4}$, which was situated on the same plate, an undisturbed place was sought out which exhibited the same opacity, and the distance of this point from the limb was determined. Since the falling off in the brightness of the Sun's disk from the center toward the edge was known from the previous investigation, this gave directly the brightness of the spot, which could then be referred to the normal brightness of the Sun at an equal distance from the limb as unity. It was only in case of the exceedingly dark spot of November 16 that no suitable opacity for comparison could be found on the plate, and a small extrapolation had to be made from the opacity-curve.

The measurements were rendered for the most part rather difficult by the fact that the nucleus of the sun-spot did not entirely fill the spot in the photometer.

Date	Distance from Center	Umbra	Penumbra	Remarks
1905				
January 17 . . .	0.72	0.21	0.52	Single spot on west limb
	0.27	0.14	0.64	Great spot group
	0.78	0.40	. . . .	Single spot on east limb
January 18 . . .	0.83	0.35	. . . .	Single spot on west limb
	0.42	0.11	0.47	Great spot group
	0.65	0.47	. . . .	Single spot on east limb
June 28	0.53	0.13	0.49	Great spot group
	0.69	0.11	0.69	Single round spot
October 16 . . .	0.73	0.032	0.52	Great group
November 9 . .	0.83	0.30	. . . .	Single spot
	0.43	0.019	0.60	Single round spot
December 25 . .	0.67	0.12	0.63	Three neighboring spots on west limb
	0.75	0.12	. . . .	
	0.88	0.55	. . .	

[1] *Astrophysical Journal*, **23**, 43, 1906.

The preceding short table gives, in addition to the date, the distance of the spot from the center of the disk in decimals of the radius, the brightness of umbra and penumbra in comparison with the brightness of an undisturbed place at equal distance from the center, and finally a few general remarks to designate the spot.

Faculæ may be followed in many instances on our plates in long curves to the exterior half of the Sun's radius, but in no place does their brightness exceed by more than 20 or 30 per cent. that of the undisturbed neighborhood.

K. SCHWARZSCHILD AND W. VILLIGER.

A THEORY FOR THE DISTRIBUTION OF SPECTRAL LINES IN SERIES

A comparatively recent attempt has been made by Professor F. von Lindemann[1] to account for the distribution of spectral lines in series. His method is to investigate the possible waves which a hypothetical atom of matter will send out into the surrounding luminiferous ether. He assumes that the atom in every case consists of elastic isotropic matter which is the same in kind for all substances, but is different in shape, size, density, and elasticity. The mathematical theory of the various modes of vibration which such a body can assume has been worked out before, but the application of the same to bodies of definite shape has been difficult because it involves the discovery of mathematical functions for each shape. The periodicity of each kind of vibration which the body sets up in the ether always occurs as a root of a certain transcendental equation involving those functions. Such an equation has an infinite number of roots, each real one corresponding to a definite spectral line. Every equation thus gives a series of lines. Each body has a number of such equations and therefore a number of such series.

Lindemann has investigated the various cases which admit of mathematical treatment, namely, where the atom is spherical, ellipsoidal, or ring-shaped. Owing to the extraordinary intricacy of the equations, no detailed calculations have yet been made from them. The solutions, for the most part, have been carried only far enough to indicate what the general type of distribution of the lines is for each case.

[1] *Sitz. Math. phys. Klasse d. Kgl. Bay. Akad.*, 31, 441, 1901; *Ibid.*, 33, 27, 1903; (Translation of Popular Lecture) *Monist*, January 1906.

In the case of a spherical atom he finds the distribution obeys a law which is simpler than any so far discovered for the elementary substances.

For an atom which has the shape of an elongated ellipsoid of revolution (a prolate spheriod) he finds that the distribution will depend upon three numbers, and hence may be arranged in groups according to three principles. These numbers occur as the roots of certain transcendental equations and are determined by the axes, density, and elasticity of the ellipsoid. The spectra of the alkali metals (lithium, potassium, cæsium, and rubidium) show this type of distribution of lines, so the atoms of these metals may be considered as having the shape of a prolate spheroid.

In the case of an oblate spheroid the spectral lines are found to be arranged according to a different law. The arrangement here resembles that of the lines in the spectra of gold, silver, and copper. The hydrogen spectrum is also of the same type.

In the more general case, where the atom is supposed to have the shape of an ellipsoid with three unequal axes, Lindemann finds that the lines do not fall into series and groups as in the other cases, but are distributed over the whole spectrum. Only when the ellipsoid approximates to a spheroid do the lines fall into series. When the prolate spheroid is approximately obtained, the distribution resembles that of the alkaline earths (barium, strontium, calcium, and magnesium); when the oblate spheroid is approached, the distribution is like that of zinc, cadmium, and mercury.

For a ring-shaped body the distribution of lines is found to resemble that of the oxygen, helium, sulphur, and selenium spectra.

A striking consequence of the foregoing theory is that which results from a change in shape of the spherical atom. The sphere can be thought of as gradually deformed by pressure until it assumes an ellipsoidal shape. By this change the theory shows that each spectral line will give rise to eight new ones. It is easy to see from this how the theory may be made to account for the Zeeman effect.

So far as comparisons have been made between this theory and the established facts, only a few points of agreement have been found. Not until more detailed calculations are made will it be possible to say how closely the theory can be made to account in detail for the distribution of lines in line-spectra.

T. S. Elston.

The Johns Hopkins University.

THE PRESENT CONDITION OF ROWLAND'S RULING MACHINES[1]

As is well known, Professor Rowland designed and had constructed under his direction three machines for the purpose of ruling diffraction gratings. The mechanism of them all was more or less identical, and that of the last is described in full, with drawings, in Rowland's *Physical Papers*, p. 689.

The screws of all three machines have twenty threads to the inch, but owing to differences in the number of teeth in the divided heads, rule gratings with different spaces, viz., 14,438, 15,020, and 20,000 lines to the inch.

Nothing is known of the inception of the idea in Rowland's mind of making these machines; but the first one was constructed in the autumn of 1881. This is the one which rules 14,438 lines to the inch. The next to be made was the one which rules 20,000 lines; and, last of all, the one which rules 15,020 lines. All these machines had been made by the same workmen; the castings were made in Baltimore; the toothed wheels, the screws, and the brass parts were all ground and worked by Theodore Schneider, the instrument-maker of this laboratory.

The first machine was too small to rule large gratings; and, further, all the gratings ruled, with few exceptions, had periodic errors, due, in part, to the fact that the toothed wheel was not solid, but had spokes. Consequently, the second machine was made with a longer screw, a solid toothed wheel, and numerous other improvements. This machine soon proved itself unsatisfactory. In fact, out of all the gratings ruled on it, only one was of the best quality. Numerous attempts were made by Schneider to improve the machine, but Professor Rowland determined to construct an entirely new one. In the meanwhile, Schneider had accidentally dropped a heavy oil-can on the screw of the smaller machine; and its usefulness was much diminished. Finally the third machine, as described above, was completed, and with it all the best gratings have been ruled. Even with it, however, the percentage of good gratings to poor ones was always small, and seemed definitely to be becoming smaller.

Schneider died in the early spring of 1901, and his place as instrument-maker of the laboratory was taken by Charles Childs. Schneider's death was followed almost immediately by that of Professor Rowland, on April 16, 1901. The machines thus came under my care; and my first duty was to have a thorough examination made of all three. The results will be given below. Soon afterwards, Mr. L. E. Jewell, who for many years had tested most of the gratings ruled before they were distributed, returned

[1] From *Johns Hopkins University Circular* No. 186; N. S., 1906, No. 4, April.

to the university; and he was entrusted with the duty of testing all the parts of the machines in detail. Since then he has been immediately in charge of the machines, and all the alterations and improvements have been carried out under his direction.

The result of the examination of the machines may be given as follows:

14,438 machine. Screw injured; divided head of faulty construction.

20,000 machines. Screw imperfect; divided head placed eccentrically on screw; thrust pin, against which screw presses, not in line with screw; the mechanism holding the diamond, too loosely jointed and having the line joining pivots out of line; the journals holding the screw too loose and out of line.

15,020 machine. Screw good; divided head correctly placed; thrust pin out of line; mechanism holding the diamond very faulty; the wooden plugs in the nut loose and in some cases decayed.

None of the machines was provided with oil-cups of any kind; the metal surfaces in contact, and where there was relative motion, were in some cases improperly chosen, and in all cases the friction was altogether too great. There were also numerous defects in the shafting, the shapes of the cams, etc., all of which were easily remedied.

It was a most serious question to know what to do in order to place the machines in working order. It was obvious that the defects in them were not in design, but in execution. During the last years of Rowland's life he had been so occupied by other investigations that he had left the entire control of the machines in the hands of others; in fact, it is doubtful if Rowland even looked at the machines for a year before he died.

It was evident that the smallest machine was useless so far as ruling diffraction gratings was concerned; and it was removed from its position in the vault and taken to one of the upper rooms. At the time of the exhibition in St. Louis in 1904, this machine was placed on view among the other pieces of apparatus of historic interest from this laboratory. Unfortunately, it was carelessly packed, and the toothed wheel was injured in transit. These bent teeth have been replaced, but no further attempt has been made to put the machine in condition.

The 20,000 machine was evidently beyond hope, except in so far as the frame could be used. All the brass parts have since been corrected or replaced; the divided head has been properly set, etc.; but, most important of all, a new screw and a new nut have been made. A few words will be said in regard to these later. This reconstructed machine has been tested and found to be nearly free from errors. Work on it is not yet completed, but it is expected that gratings will be ruled within a fortnight.

One of the most important modifications has been to introduce an antifriction alloy on the two platforms, and to attach counterbalancing weights to the platform which carries the grating, so as to diminish pressure and friction on the ways when heavy gratings are placed on the platform. Numerous devices of less importance have also been introduced.

The 15,020 machine was in the best condition of the three, although that was far from being satisfactory. It was determined to make as many simple corrections as were possible, to exercise better care in the choice of ruling points, to maintain a more constant temperature, and not to attempt to rule any more large gratings than were absolutely necessary. Unfortunately, this last determination was not adhered to at first, and disastrous consequences resulted; more of the wooden plugs in the nut became loosened. These were tightened temporarily, and many gratings have been ruled. A much larger percentage of these are good than was ever the case in previous years; and the best are so far better than the highest grade that was formerly produced that an entirely new quality had to be described and listed. As soon as the new 20,000 machine is working properly, this machine will be taken apart and reshaped. The most important improvement will be a new nut.

A few words should be said in regard to the new screw and nut of the 20,000 machine. A full description will be published as soon as facts in regard to its actual use are at hand. The screw was cut on a Reed lathe, and was ground by a special nut, made of a fusible metal and *cast on the screw* itself. Similarly, the ruling nut, like the grinding one, was cast on the screw. The advantages over the wooden plug nut as used on the old machines are obvious; chief among them are the saving of time in grinding and the diminution of error owing to differential expansion, due to temperature changes between screw and nut.

The new screw and nut were designed by Mr. Jewell and were made by Childs; and both for this and for the other improvements in the machines all those interested in the science of spectroscopy owe a debt of gratitude to Mr. Jewell's great ingenuity and to Child's mechanical skill.

J. S. AMES.

PROFESSOR ERNST ABBE

Rochester, N. Y., March 22, 1906.

A little more than a year ago there died in Jena, that world-famous town, Professor Ernst Abbe, who has had no small share in making Jena so well known to the entire civilized world.

At the time of his death, papers and magazines contained full accounts of the life and work of this truly remarkable man, reciting in detail his numerous contributions to science and his successful experiment in organizing an industrial enterprise upon distinctively new lines.

Since that time the feeling that here was a man whose work has been for the good of mankind and whose memory should be fittingly honored, gathered strength until there was appointed a committee to take charge of soliciting funds for the purpose of erecting in his native town, between the Volkshaus erected by him and the Zeiss Works, a statue as a memorial.

The names of a number of American scientists and business men who had had dealings with the Zeiss Works were included in the committee named. We in America seem very far off from the little German town where the statue to Abbe is to be placed; and one might think it of little account whether we help to erect the statue or not. But this is a unique occasion, as Abbe was a unique man, and most of us who know anything at all about him will consider it a privilege to be able to contribute, be it ever so small a sum, to the statue that is to perpetuate his form to posterity.

The undersigned have for many years had business relations with Professor Abbe through the Carl Zeiss Works. They have, therefore, a strong desire, a desire tinged by personal acquaintance, to see America well represented in this memorial. They believe that many will be glad to avail themselves of the opportunity of giving something to show their appreciation of the great work done by Abbe and in order that such opportunity may not be wanting they have arranged, with the consent of the other members, to act as secretary and treasurer of the American Committee to solicit funds for this purpose.

Under date of February 25th the American Microscopical Society issued a circular letter appealing to their members to aid in this movement. We would state that we have no desire to interfere in any

way with the collections that might be made by the Society, in fact we would urge, since our purpose is only to help increase the fund, that all contributions of members or others interested in the Society be sent direct to them, since it is eminently fitting that such an organization should make as good a showing as possible.

We urgently request all others who are interested to send contributions to us, be they large or small, and ask all to assist by giving as much publicity as possible to the scheme, and by endeavoring to arouse interest and enthusiasm in the project.

We shall make personal acknowledgment immediately upon receipt of contributions and shall publish list of contributors as soon as the total amount is forwarded to Germany.

BAUSCH & LOMB OPTICAL CO.

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THE SYSTEM OF *CASTOR*

By HEBER D. CURTIS

With the exception of two early spectrograms of the brighter component, all the plates used in this paper were taken with the remounted Mills spectrograph, λ 4500 central. Both components are of the Sirian type, catalogued in the Harvard classifications as *A* and VIII *a*. The absorption is somewhat more complete in α_1, the fainter component, than in α_2. The number of measurable lines is accordingly somewhat greater in α_1, the average being thirty-four, as against twenty-four for α_2. Although the lines in α_2 are not so distinctly defined, yet when the proper exposure is secured, the measures seem to be somewhat more accurate on this star than on α_1. In the table given herewith are placed the lines used in in the investigation, with their adopted wave-lengths.

It was found advantageous to employ a slit rather longer than is usually the practice with the Mills spectrograph, and the exposures which gave the best plates under average atmospheric conditions were eighteen and forty-four minutes for the brighter and fainter components, respectively.

It is not to be understood that the lines marked "lacking" in α_2 do not occur, but that they are too indistinct for measurement. All lines used in this part of the spectrum of α_1 are thought to occur in α_2, although the less complete absorption in the latter star renders the fainter lines very indistinct, and for some lines seems

to leave no trace at all except on one or two plates whose exposure conditions were most favorable.

TABLE OF WAVE-LENGTHS

λ	Description	a_1	a_2	Notes
4367.839	*Ti* 2	Occasional	Faint or lacking	
74.99	*Ti* enhanced		Diff. or lacking	Gives constant negative residuals; wave-length about 4374.92
83.720	*Fe* 15			
85.548	*Fe* enhanced		Lacking	
87.007	*Ti*? 1	Rare		One or two plates only
95.201	*Ti* 3 enhanced			
99.935	*Ti Cr* 3 enhanced			
4404.927	*Fe* 10 enhanced			
15.293	*Fe* 10 enhanced			
16.985	2			
17.884	*Ti* 3 enhanced			
43.976	*Ti* 5 enhanced		Gen. poor	Rather untrustworthy
50.654	*Ti*(?) 2 enhanced		Gen. lacking	
59.301	*Fe* 3		Lacking	
64.617	*Ti* 2 enhanced	Occasional	Lacking	One plate only
66.727	*Fe* 5	Occasional	Lacking	Difficult
68.663	*Ti* 5 enhanced			
76.185	*Fe* 5		Gen. lacking	
81.400	*Mg*			Always strong
89.351	?	Poor	Occasional	
91.570	2 *Fe*? enhanced			Frequently too difficult to use
94.738	*Fe* 6	Rare	Lacking	
4501.448	*Ti*-5 enhanced			Always strong
08.455	*Fe* ?-4 enhanced			
15.501	*Fe* enhanced			
20.397	*Fe* ?-3 enhanced			
22.802	*Fe*			
25.314	*Fe* 5	Rare	Lacking	
28.798	*Fe* 8	Occasional	Lacking	
34.139	*Ti-Co* 6 enhanced			Generally good
41.690	*Cr* 2	Occasional	Gen. lacking	
49.642	*Fe* 2 enhanced			Strongest line in this part of the spectrum
54.211	*Ba* 8		Difficult	
56.070	*Fe* enhanced		Difficult	
58.827	*Cr*? 3			
63.939	*Ti* 4 enhanced			
72.156	*Ti*-6 enhanced			
76.512	*Ti*? enhanced		Lacking	
83.011	1	Occasional	Lacking	
84.018	*Fe* 4 enhanced			
88.381	3			
90.114			Occasional	
92.840	*Fe* 4		Rare	
4618.971	*Fe*-4d?			
29.521	*Ti-Co* 6			

The intensities in column 2 are as given in Rowland's table for the Sun. The star lines vary greatly from this scale.

α_1 *GEMINORUM*

(Fainter component; south preceding; magn. = 3.7)

The binary character of this component of *Castor* was discovered by Professor Belopolsky at Pulkova in 1896.[1] In his last paper Belopolsky has considered several hypotheses as to the orbit of this system, to which reference will be made later.

The Lick Observatory plates of this component are as follows:

No.	Plate	G. M. T.	Velocity	Notes
1	3492 D	1904. October 18.007	+20.5 km	
2	3540 B	November 9.077	−13.6	
3	3546 F	9.938	+30.8	
4	3559 D	22.043	+24.5	
5	3566 A	22.817	−25.3	
6	3571 F	23.077	−31.3	Poor plate; wt. ½
7	3582 D	29.056	−30.8	
8	3586 D	29.842	+ 3.9	
9	3593 B	December 6.053	+23.9	Focus poor; wt. ½
10	3603 D	7.072	+ 1.9	
11	3613 D	8.075	−27.8	
12	3621 B	14.014	−24.7	
13	3632 E	27.940	−21.5	
14	3637 D	1905, January 1.980	+27.6	
15	3641 B	2.677	−15.1	
16	3646 A	2.973	−29.8	
17	3653 C	4.965	+21.9	
18	3656 B	9.906	+ 9.1	
19	3662 C	11.013	+14.1	
20	3665 D	February 13.714	−13.3	Comparison weak
21	3674 C	20.889	+20.7	Lines broad
22	3685 B	25.791	+ 8.4	Focus not very sharp
23	3695 B	27.749	−32.6	
24	3698 E	27.898	−35.9	Focus poor; wt. ½
25	3702 A	28.662	+ 5.7	
26	3706 D	28.880	+18.0	
27	3714 E	March 1.763	+15.2	
28	3717 B	1.881	+ 7.2	
29	3725 E	5.722	−33.0	
30	3729 C	5.858	−31.7	
31	3759 B	April 2.715	+27.1	
32	3794 A	May 15.694	− 0.2	

Although the Lick Observatory plates cover a period of nearly seven months, it did not seem advisable to determine the period

[1] *Bulletin* of the Acad. of Sciences of St. Petersburg, December 1896; *Astrophysical Journal*, **5**, 1, 1896; *Mem. Acad. Sci., St. Petersburg*, **11**, No. 4, 1900.

from this series alone, but to use the maxima and minima secured by Belopolsky in the years 1896–1899, in connection with the present series. From these a period of 2.928285 days was adopted, which satisfies my observations very well. This value cannot be very much in error, and any attempt to correct it in the least-square solution would be meaningless, without a much more extended series of observations. Accordingly no term for the correction to the period was included in the solution.

With this value of the period a preliminary orbit was derived by the method of Lehmann-Filhés,[1] giving the following set of elements:

PRELIMINARY ELEMENTS

Period = 2.928285 days
T = J. D. 2416827.969
$\omega = 92\overset{\circ}{.}695$
$e = 0.08$
$K = 31.7$
$\mu^{\circ} = 122\overset{\circ}{.}939$
Velocity of system = −0.80 km

From these elements differential coefficients were computed which, when rendered homogeneous, gave the following equations of condition:

	δV	δT	δK	$\delta\omega$	δe	n
1....	$+1.000x$	$+0.694y$	$+0.685z$	$-0.805u$	$+1.000v$	$-0.114=0$
2....	+1.000	−0.692	−0.350	+0.858	+0.639	−0.431
3....	+1.000	−0.237	+0.952	+0.212	−0.572	+0.351
4....	+1.000	+0.496	+0.841	−0.615	+0.875	−0.337
5....	+1.000	+0.587	−0.791	−0.697	−0.977	+0.141
6....	+0.707	+0.041	−0.708	−0.103	−0.122	+0.213
7....	+1.000	−0.165	−0.984	+0.116	+0.330	+0.300
8....	+1.000	−0.720	+0.134	+0.910	−0.214	+0.101
9....	+0.707	−0.375	+0.505	+0.436	−0.667	+0.366
10....	+1.000	+1.000	+0.051	−1.079	+0.160	+0.262
11....	+1.000	−0.488	−0.784	+0.546	+0.915	−0.532
12....	+1.000	−0.567	−0.674	+0.662	+0.942	−0.631
13....	+1.000	+0.618	−0.767	−0.726	−0.990	+0.901
14....	+1.000	+0.377	+0.906	−0.494	+0.713	−0.082
15....	+1.000	+0.824	−0.547	−0.920	−0.895	+0.757
16....	+1.000	+0.259	−0.962	−0.366	−0.577	+0.356
17....	+1.000	+0.492	+0.844	−0.610	+0.871	−1.000
18....	+1.000	−0.705	+0.256	+0.885	−0.432	+0.450
19....	+1.000	+0.831	+0.521	−0.931	+0.919	−0.396
20....	+1.000	−0.693	−0.343	+0.861	+0.628	−0.399

[1] *Astronomische Nachrichten*, 136, 17, 1894.

	δV	δT	δK	$\delta\omega$	δe	n
21....	$+1.000x$	$+0.630y$	$+0.743z$	$-0.745u$	$+0.984v$	$-0.507=0$
22....	$+1.000$	-0.694	$+0.315$	$+0.868$	-0.530	-0.186
23....	$+1.000$	-0.017	-1.004	-0.060	-0.007	-0.002
24....	$+0.707$	-0.191	-0.670	$+0.177$	$+0.397$	-0.879
25....	$+1.000$	-0.711	$+0.214$	$+0.896$	-0.358	-0.064
26....	$+1.000$	-0.607	$+0.580$	$+0.731$	-0.877	$+0.114$
27....	$+1.000$	$+0.786$	$+0.582$	-0.890	$+0.967$	-0.614
28....	$+1.000$	$+0.936$	$+0.324$	-1.025	$+0.662$	-0.567
29....	$+1.000$	-0.219	-0.968	$+0.184$	$+0.451$	-0.381
30....	$+1.000$	-0.412	-0.859	$+0.439$	$+0.823$	-0.903
31....	$+1.000$	$+0.292$	$+0.942$	-0.405	$+0.568$	-0.498
32....	$+1.000$	-0.727	$+0.024$	$+0.920$	-0.011	-0.052

In the above equations

$$x=\delta V$$
$$y=[1.9028]\delta T$$
$$z=\delta K$$
$$u=[1.5011]\delta\omega$$
$$v=[1.5164]\delta e$$

Log "unit error" $=0.6064$

The resulting normal equations were:

$[a\,a]$	$[a\,b]$	$[a\,c]$	$[a\,d]$	$[a\,e]$	$[a\,n]$
$+30.500x$	$+0.797y$	$-0.737z$	$-0.920u$	$+5.730v$	$-4.175=0$
	$+11.150$	$+2.656$	-13.114	$+2.422$	$+0.351$
		$+14.941$	-2.836	$+2.701$	-1.358
			$+15.509$	-2.967	-0.324
				$+15.508$	-8.761
					$+7.513$

The solution gave:

$$\delta V'=-0.14 \text{ km}$$
$$\delta T'=+0.029 \text{ days}$$
$$\delta K'=-0.102$$
$$\delta\omega'=+2^\circ.508$$
$$\delta e'=-0.0702$$

whence the elements

I

Period $=2.928285$

$T=$ J. D. 2416827.998

$e=0.0098$

$\mu^\circ=122^\circ.939$

$\omega=95.203$

$K=31.598$

$V=-0.94$ km

The sum of the squares of the weighted residuals has been reduced from 122.6 to 37.6. All the changes in the elements secured from the solution are small, with the exception of that for the eccentricity, which is reduced from 0.08 to 0.01. The result is that the terms of the second order are not negligible, and there is a lack of agreement between the change in the residuals secured by computing an ephemeris from these elements and by substituting the values of the unknowns directly in the equations of condition. This lack of agreement amounts in several cases to 0.3 km. A second solution therefore became necessary. This solution was based on the ephemeris secured from Elements I. The differential coefficients, when reduced to homogeneity, form the following equations of condition:

	δV	δT	δK	$\delta\omega$	δe	n
1....	+1.000x	+0.774y	+0.629z	−0.787u	+0.997v	+0.561=0
2....	+1.000	−0.878	−0.416	+0.900	+0.807	+0.167
3....	+1.000	−0.175	+0.983	+0.169	−0.435	+0.257
4....	+1.000	+0.612	+0.787	−0.626	+0.948	+0.216
5....	+1.000	+0.706	−0.707	−0.718	−0.999	−0.751
6....	+0.707	+0.154	−0.690	−0.163	−0.362	+0.115
7....	+1.000	−0.039	−1.000	+0.030	−0.012	+0.654
8....	+1.000	−0.954	+0.133	+0.981	−0.177	+0.223
9....	+0.707	−0.435	+0.546	+0.442	−0.701	+0.126
10....	+1.000	+0.100	+0.060	−1.008	+0.212	+0.342
11....	+1.000	−0.502	−0.858	+0.506	+0.836	+0.093
12....	+1.000	−0.637	−0.755	+0.646	+0.971	+0.034
13....	+1.000	+0.731	−0.682	−0.743	−0.991	+0.379
14....	+1.000	+0.506	+0.859	−0.521	+0.833	+0.517
15....	+1.000	+0.884	−0.469	−0.894	−0.776	+0.257
16....	+1.000	+0.422	−0.906	−0.436	−0.827	−0.104
17....	+1.000	+0.608	+0.789	−0.623	+0.945	−0.769
18....	+1.000	−0.926	+0.273	+0.952	−0.446	+0.539
19....	+1.000	+0.878	+0.475	−0.890	+0.887	+0.019
20....	+1.000	−0.882	−0.408	+0.903	+0.797	+0.130
21....	+1.000	+0.723	+0.686	−0.737	+0.019	−0.011
22....	+1.000	−0.906	+0.339	+0.930	−0.565	−0.494
23....	+1.000	+0.137	−0.991	−0.149	−0.361	−0.141
24....	+0.707	−0.125	−0.696	+0.120	+0.189	−1.000
25....	+1.000	−0.938	+0.224	+0.964	−0.354	−0.152
26....	+1.000	−0.747	+0.633	+0.763	−0.955	−0.375
27....	+1.000	+0.845	+0.531	−0.857	+0.941	−0.245
28....	+1.000	+0.955	+0.298	−0.964	+0.646	−0.480
29....	+1.000	−0.108	−0.995	+0.100	+0.130	−0.238
30....	+1.000	−0.381	−0.922	+0.381	+0.652	−0.595
31....	+1.000	+0.426	+0.901	−0.441	+0.718	−0.175
32....	+1.000	−0.962	+0.007	+0.990	+0.073	+0.175

The factors for homogeneity in this second set of equations are:

$$x=\delta V$$
$$y=[1.8391]\delta T$$
$$z=\delta K$$
$$u=[1.4997]\delta\omega$$
$$v=[1.4997]\delta e$$

Log "unit error" $=0.4298$

The resulting normal equations are:

$[a\,a]$	$[a\,b]$	$[a\,c]$	$[a\,d]$	$[a\,e]$	$[a\,n]$
$+30.500x$	$+0.885y$	$-1.096z$	$-0.897u$	$+3.896v$	$-0.504=0$
	$+15.288$	$+2.372$	-15.593	$+2.215$	-0.188
		$+14.616$	-2.379	$+2.931$	$+0.920$
			$+15.900$	-2.269	$+0.200$
				$+15.335$	$+0.120$
					$+5.232$

The solution of these equations gives:

$$\delta V''=-0.04 \text{ km}$$
$$\delta T''=+0.059 \text{ days}$$
$$\delta K''=+0.164$$
$$\delta\omega''=+7^\circ.313$$
$$\delta e''=+0.00001$$

FINAL ELEMENTS

Period $=2.928285$ days

$T=$ J. D. 2416828.057 ± 0.042 days

$e=0.01 \qquad \pm 0.0066$

$\mu^\circ=122^\circ.939$

$\omega=102^\circ.516 \qquad \pm 5^\circ.120$

$K=31.76 \qquad \pm 0.22$

$V=-0.98$ km $\qquad \pm 0.15$ km

$a \sin i=1,279,000$ km

$[p\,v\,v]$ equations $=37.3$

$[p\,v\,v]$ ephemeris $=37.6$

An ephemeris computed with circular elements gave $[pvv]=40.6$.

The second solution is satisfactory. In the annexed table are given the residuals computed from these elements, and also the comparison between the change in the residuals secured from the

ephemeris and that resulting from direct substitution in the equations of condition.

No.	O.–C.	Equat.–Eph.	No.	O.–C.	Equat.–Eph.
1......	+1.49	–0.02	17......	–2.13	+0.01
2......	+0.50	–0.01	18......	+1.35	–0.02
3......	+0.60	0.00	19......	+0.01	+0.03
4......	+0.52	+0.02	20......	+0.55	+0.05
5......	–1.87	+0.03	21......	–0.07	0.00
6......	+0.67	+0.01	22......	–1.45	+0.03
7......	+1.99	–0.01	23......	–0.15	+0.01
8......	+0.52	+0.02	24......	–3.57	0.00
9......	+0.40	–0.01	25......	–0.50	–0.02
10......	+0.95	0.00	26......	–1.14	+0.03
11......	+0.43	0.00	27......	–0.71	+0.02
12......	+0.25	–0.01	28......	–1.30	0.00
13......	+1.17	+0.02	29......	–0.41	+0.01
14......	+1.33	+0.01	30......	–1.41	+0.01
15......	+0.80	–0.02	31......	–0.55	–0.02
16......	–0.07	+0.03	32......	+0.41	+0.01

The probable error of a single plate is ± 0.79 km.

The observations, together with the velocity-curve, are platted in Fig. 1.

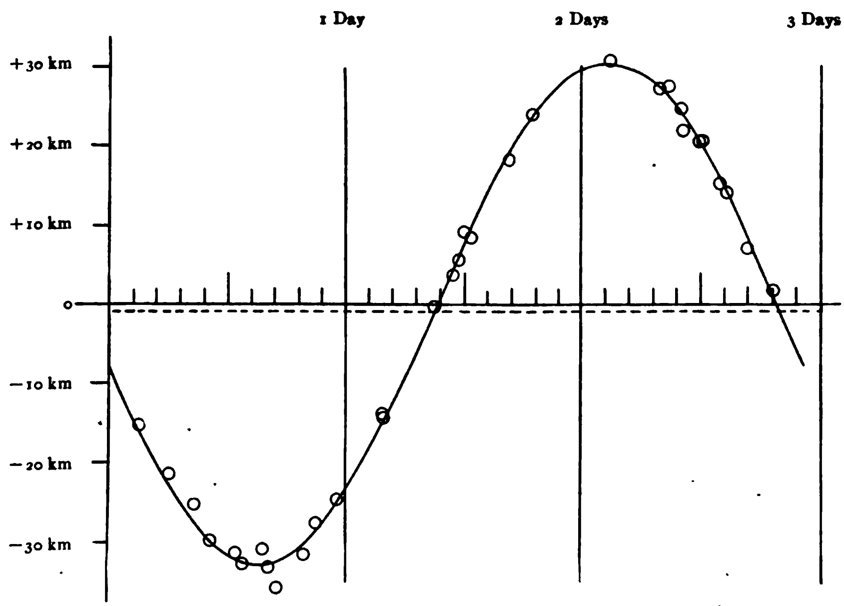


FIG. 1.—Velocity-Curve of α_1 *Geminorum*

The radius of the small circles represents the probable error of a plate. The dotted line represents the velocity of the center of mass of the system.

The only other published spectrographic observations of α_1 *Geminorum* known to the writer are the 118 made by Professor Belopolsky. For completeness they are given here, with the Julian Day of Greenwich Mean Time, and the velocity reduced to kilometers.

Jul. Day G. M. T.	Velocity	Jul. Day G. M. T.	Velocity
1894 2412926.31	+21.2 km	1897 2414224.45	+ 1.1 km
30.28	− 5.8	29.43	+14.1
1896 3560.35	−27.4	30.43	+ 6.1
79.37	+20.6	41.41	+31.5
97.35	+21.7	90.46	−15.4
3605.37	+ 1.4	1898 4292.47	−25.0
9.38	+18.8	4310.40	−25.5
12.34	+11.6	11.43	+26.3
13.34	−33.8	18.45	− 3.2
14.34	+ 1.4	19.40	−29.3
15.25	+16.2	21.40	− 5.0
16.28	−45.5	38.41	+15.3
17.29	− 0.8	42.39	−34.1
27.28	+ 1.0	64.26	+15.0
28.24	−37.8	65.26	− 6.5
30.24	+ 2.9	74.29	−18.0
33.30	− 9.5	75.29	−20.0
35.25	+26.4	76.29	+21.7
43.25	−18.5	77.28	−20.8
48.30	−25.9	91.26	+14.0
49.27	+ 1.9	93.26	+ 5.9
50.28	+28.9	94.26	+ 8.2
51.28	−45.0	95.25	−36.8
53.28	+22.9	95.28	−37.2
57.28	−40.1	96.33	+22.8
58.28	+ 8.8	4403.29	− 4.6
61.26	+ 7.5	4.27	−32.7
64.27	+16.2	5.27	+22.7
67.37	+17.8	8.27	+25.5
69.31	−31.4	9.27	−10.2
70.31	+20.6	11.27	+31.2
72.33	−16.5	12.27	−13.5
74.37	−17.4	14.28	+31.5
76.32	+34.7	4612.47	−25.4
1897 4021.28	+ 2.7	1899 74.40	+14.5
22.28	+31.5	79.38	−29.2
24.27	+ 7.8	79.41	−28.3
25.28	+ 8.3	79.43	−28.1
28.28	+13.1	83.37	+19.9
30.28	+ 7.7	83.39	+22.9 *
31.27	+ 4.9	83.42	+25.2

*The means of the bracketed measures were used by Professor Belopolsky.

Jul. Day G. M. T.	Velocity	Jul. Day G. M. T.	Velocity
1899 2414690.34	− 7.5km	1899 2414721.23	+ 8.6km
90.36	− 0.7	21.31	+12.8
90.38	− 6.8	22.22	+19.8
90.41	−11.4	22.24	+ 6.8
92.38	+27.1	24.22	+ 6.2
92.40	+36.8	24.25	+16.8
92.42	+26.3	27.30	+19.8
95.33	+35.3	29.32	−27.7
95.36	+24.6	34.23	− 5.1
95.38	+29.3	34.26	− 3.3
4709.33	− 4.2	40.24	−13.6
9.38	+ 6.0	40.26	−11.7
9.40	+ 1.5	54.25	+24.6
16.39	+11.6	57.27	+21.2
16.41	+17.3	57.38	+21.2
16.44	+ 8.4	59.31	+ 7.4
19.23	+17.4	61.31	−28.1
20.29	−35.3		
20.30	−31.7		

This extended series has been of great value in determining the period of α_1 by comparison with the Lick Observatory plates. They were made, however, in the early days of spectrographic velocity determinations, so that naturally the standard of accuracy is much lower than is now attained. These plates have been investigated by Dr. Belopolsky in his paper, "Bearbeitung der in Pulkova erhaltenen Spectrogramme von dem Spectral-Doppelstern α_1 *Geminorum.*"[1]

Dr. Belopolsky separated the plates into three groups, and tested a number of different sets of elements. He considers it probable that there is a rotation of the line of apsides. The elements which give the smallest sum of the squares of the residuals are as follows: (Belopolsky's tenth hypothesis, *loc. cit.*, p. 83):

BELOPOLSKY'S ELEMENTS

$V = -4.1$ km
$K = 33.43$
$e = 0.12$
Period $= 2.934050$ days
$\omega = 82°$ at the epoch 1896, Jan. $0^d.0$
$\Delta\omega = 0°.239726$ per day
Period of rotation of line of apsides $= 1502$ days
$[v\,v] = 2450$
Probable error of a plate, series of 1899 $= \pm 2.45$ km
Probable error of a plate for entire series $= \pm 3.41$ km

[1] *Mém. de. l'Acad. Imp. des Sciences de St. Petersburg*, 11, No. 4, 1900.

Dr. Belopolsky states that he does not regard the observational data as sufficient for definitive decision as to whether the assumed change in the orbital elements is real or not. The sum of the squares of the residuals for a circular orbit is not very much in excess of that for an elliptical orbit. From the present solution, it is evident that the orbit is nearly a circle. The greatest effect of a rotation of the line of apsides of the present orbit, eccentricity of 0.01, will

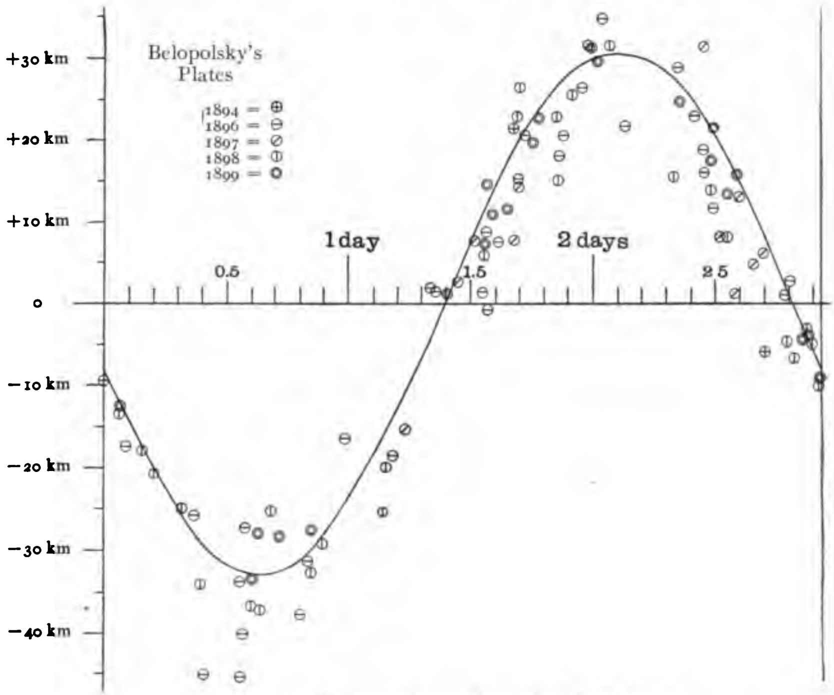


FIG. 2.—Pulkova observations of α_2 *Geminorum*

be but ± 0.3 km in the radial velocity. This cannot be detected with certainty by present methods in stars of this spectral type. The assumption of any rotation of the line of apsides must accordingly be definitely abandoned for the present.

In Fig. 2 are plotted the Pulkova observations on the velocity-curve derived from my final elements. The constant difference between the Pulkova and Lick Observatory plates shown in the figure amounts to about 3 km. Such is the uncertainty in the orbit of the visual system of *Castor* that no safe conclusion can be reached

as to the variation in the relative velocities of α_1 and α_2 in the nine years which intervened between the earlier plates of the Pulkova series and those secured at Mount Hamilton, but this difference is certainly very small and entirely insufficient to account for the difference in position of the two velocity-curves. If we accept Doberck's recent orbit with period of 347 years, the difference of the radial velocities for 1896.4 and 1904.9 will be but 0.4 km. Belopolsky's published observations for 1899 are in general the mean of several plates. These observations are much more accurate than his earlier ones, and it will be seen that they fall, as a rule, fairly close to the Lick Observatory curve.

The radii of the small circles in Fig. 2 are not equal to the probable errors of a plate, as in the other diagrams given in this paper.

α_2 *GEMINORUM*

(Brighter component; north following; mag. = 2.7)

The variation in the radial velocity of this component of *Castor* was discovered by the writer in October 1904.[1] The observations used in this discussion are given in the accompanying table. They include all the Lick Observatory plates, except two taken under poor conditions, which are so weak as to be worthless.

No.	Plate	Date G. M. T.	Velocity*	Notes
1	555 D	1897, November 18.975	+ 1.1 km	Poor plate
2	2063 C	1901, March 31.740	+17.3	Very poor; wt. ½
3	3465 E	1904, September 28.025	+ 2.9	
4	3539 A	November 9.053	+17.7	
5	3545 E	9.913	+15.9	
6	3558 C	22.015	+ 4.4	
7	3565 F	22.791	+ 0.9	
8	3570 E	23.056	− 1.4	
9	3581 C	29.025	+12.4	
10	3585 C	29.819	+ 9.5	
11	3592 A	December 6.025	+19.0	
12	3602 C	7.042	+17.4	
13	3612 C	8.049	+12.7	
14	3620 A	13.986	− 3.4	Focus poor; wt. ½
15	3627 C	26.941	+12.4	
16	3631 D	27.915	+ 9.1	
17	3636 C	1905, January 1.955	+ 9.5	
18	3640 A	2.652	+18.2	Weak plate; wt. ½
19	3647 B	2.994	+17.2	
20	3650 B	3.951	+16.1	

* The velocities for plates 1, 2, 3, 4, 9, 14, 15, 16, 30, and 31 are the weighted means of two separate measures of the same plate. The weights are determined by the number of lines used.

[1] *Publications A. S. P.*, 17, 24, 1905; *Lick Obs. Bulletin* No. 70, 1905.

No.	Plate	Date G. M. T.			Velocity*	Notes
21........	3652 B	1905,	January	4.938	+11.2 km	
{	3655 A			9.875	− 8.5 }	Comparison poor
{	3658 D			10.072	− 9.0 }	" "
22........	Mean			9.974	− 8.7	Wt. 1
{	3661 B			10.997	+ 5.8 }	
{	3663 D			11.049	+ 6.4 }	Wt. 2
23........	Mean			11.023	+ 6.1	
{	3673 B		February	20.850	+ 9.1 }	
{	3675 D			20.932	+ 8.1 }	
24........	Mean			20.891	+ 8.6	Wt. 2
25........	3678 A			24.626	− 5.2	Weak plate; wt. ½
{	3679 A			25.610	− 6.4 }	Over-exposed
{	3680 B			25.625	− 6.2 }	
26........	Mean			25.618	− 6.3	Wt. 2
27........	3684 A			25.757	− 5.0	Comparison weak
28........	3688 A			25.956	− 1.3	
{	3691 E			26.605	+16.4 }	
{	3692 F			26.621	+17.5 }	
29........	Mean			26.613	+16.9	Wt. 2
30........	3699 A			27.927	+16.0	
31........	3707 F			28.910	+14.7	
32........	3713 D		March	1.738	+ 9.7	
33........	3718 C			1.909	+ 8.4	
34........	3720 F			2.609	+ 5.9	
{	3721 E			3.603	+ 4.6 }	Weak toward violet
{	3722 F			3.620	+ 4.2 }	
35........	Mean			3.612	+ 4.4	Wt. 2
{	3723 C			5.654	− 4.6 }	
{	3724 D			5.676	− 5.0 }	
{	3730 A			5.886	− 5.8 }	
36........	Mean			5.735	− 5.1	Wt. 3
37........	3734 B			6.718	− 8.3	
38........	3737 D			6.838	− 6.4	
{	3743 C			7.656	+14.6 }	
{	3744 D			7.676	+13.8 }	
39........	Mean			7.666	+14.2	Wt. 2
40........	3758 A		April	2.726	− 6.2	

*The velocities for plates 1, 2, 3, 4, 9, 14, 15, 16, 30, and 31 are the weighted means of two separate measures of the same plate. The weights are determined by the number of lines used.

A preliminary orbit was computed by the method of Lehmann-Filhés. This was tested and changed until it satisfied the observations fairly well. The adopted preliminary elements are as follows:

PRELIMINARY ELEMENTS

Period = 9.21898 days

T = J. D. 2416746.370

$\omega = 265^\circ.350$

$K = 13.65$

$e = 0.50$

$V = +6.20$ km

$\mu = 39^\circ.04987$

An ephemeris was computed from these elements and made the basis for the derivation of the differential coefficients. The equations of condition, in their homogeneous form, are:

No.	δV	δT	$\delta\mu$	δK	$\delta\omega$	δe	n
1.....	$+1.000x$	$-0.975y$	$-1.000z$	$-0.240u$	$+0.987v$	$-0.293w$	$-1.000=0$
2.....	+0.707	+0.076	+0.040	+0.607	+0.029	−0.421	−0.237
3.....	+1.000	+0.118	0.000	−0.240	−0.321	+0.292	−0.038
4.....	+1.000	+0.108	−0.002	+0.859	+0.041	−0.594	−0.102
5.....	+1.000	+0.120	−0.002	+0.619	−0.169	−0.644	+0.688
6.....	+1.000	+0.110	−0.003	−0.151	−0.301	+0.175	+0.161
7.....	+1.000	+0.124	−0.003	−0.368	−0.298	+0.436	−0.156
8.....	+1.000	+0.128	−0.003	−0.446	−0.277	+0.515	−0.791
9.....	+1.000	+0.115	−0.003	+0.443	−0.255	−0.500	+0.145
10.....	+1.000	+0.111	−0.003	+0.222	−0.312	−0.271	+0.140
11.....	+1.000	−0.035	+0.001	+0.956	+0.385	+0.081	−0.118
12.....	+1.000	+0.019	−0.004	+0.769	−0.059	−0.669	+0.393
13.....	+1.000	+0.116	−0.004	+0.486	−0.235	−0.550	−0.086
14.....	+0.707	−0.376	+0.013	−0.566	+0.542	−0.667	+0.511
15.....	+1.000	+0.113	−0.004	+0.363	−0.278	−0.430	+0.677
16.....	+1.000	+0.110	−0.004	+0.107	−0.327	−0.132	+0.764
17.....	+1.000	−0.398	+0.037	+0.280	+0.965	+0.715	−0.301
18.....	+0.707	−0.036	+0.002	+0.674	+0.288	+0.095	−0.371
19.....	+1.000	+0.066	−0.003	+0.939	+0.199	−0.347	−0.952
20.....	+1.000	+0.121	−0.005	+0.698	−0.117	−0.672	+0.215
21.....	+1.000	+0.115	−0.005	+0.423	−0.259	−0.491	−0.420
22.....	+1.000	+0.079	−0.004	−1.020	+0.198	+0.271	−0.538
23.....	+1.414	−1.414	+0.064	−0.089	+1.414	+0.101	+0.554
24.....	+1.414	+0.157	−0.010	+0.276	−0.447	−0.339	−0.204
25.....	+0.707	+0.098	−0.006	−0.635	−0.008	+0.445	+0.436
26.....	+1.414	−0.479	+0.031	−1.304	+0.915	−1.126	+0.086
27.....	+1.000	−0.564	+0.036	−0.776	+0.785	−0.952	−0.387
28.....	+1.000	−0.891	+0.057	−0.431	+0.947	−0.644	−0.855
29.....	+1.414	−0.528	+0.034	+1.127	+0.987	+1.189	−0.113
30.....	+1.000	+0.117	−0.008	+0.793	−0.036	−0.659	−0.543
31.....	+1.000	+0.117	−0.008	+0.516	−0.222	−0.575	+0.802
32.....	+1.000	+0.112	−0.007	+0.293	−0.297	−0.353	−0.258
33.....	+1.000	+0.111	−0.007	+0.248	−0.307	−0.302	−0.613
34.....	+1.000	+0.111	−0.007	+0.065	−0.331	−0.081	−0.619
35.....	+1.414	+1.371	−0.091	−0.286	−0.461	+0.621	+0.721
36.....	+1.732	+0.247	−0.017	−1.492	−0.085	+1.152	+0.382
37.....	+1.000	−0.187	+0.013	−0.995	+0.531	−0.551	−0.511
38.....	+1.000	−0.340	+0.023	−0.922	+0.648	−0.797	−0.027
39.....	+1.414	−0.886	+0.060	+0.852	+1.194	+1.414	−0.151
40.....	+1.000	+0.121	−0.010	−0.967	+0.082	+0.500	+0.430

The factors for homogeneity in these equations are:

$$x=\delta V$$
$$y=[1.5075]\delta T$$
$$z=[5.0615]\delta\mu$$
$$u=\delta K$$
$$v=[1.3107]\delta\omega$$
$$w=[1.3418]\delta e$$

Log "unit error" $=0.2695$

The resulting normal equations are:

[a a]	[a b]	[a c]	[a d]	[a e]	[a f]	[a n]
$+46.000x$	$-3.684y$	$-0.802z$	$+0.800u$	$+6.915v$	$-3.284w$	$-1.736=0$
	$+8.716$	$+0.543$	$+0.641$	-8.864	$+0.404$	$+2.585$
		$+1.026$	$+0.252$	-0.552	$+0.242$	$+0.870$
			$+18.623$	-1.688	-0.825	-0.623
				$+11.606$	$+0.476$	-2.545
					$+14.951$	$+0.903$
						$+9.721$

The solution of these equations gives for the corrections to the elements:

$\delta V=-0.003$ km	± 0.167 km
$\delta T=+0.0147$ days	± 0.021
$\delta\mu=+0.0000116$	± 0.0000081
$\delta K=-0.0932$	± 0.218
$\delta\omega=+0.0000455$ radians	± 0.0302 radians
$=+0\overset{\circ}{.}003$	$\pm 1\overset{\circ}{.}730$
$\delta e=+0.0033$	± 0.0112

FINAL ELEMENTS

$V=+6.20$ km	± 0.17 km
$T=$ J. D. 2416746.385	± 0.021 days
$K=13.557$	± 0.218
$\omega=265\overset{\circ}{.}353$	$\pm 1\overset{\circ}{.}730$
$e=0.5033$	± 0.0112
$\mu=39\overset{\circ}{.}05053$	± 0.00046
Period $=9.218826$ days	± 0.000108
$a \sin i=1{,}485{,}000$ km	
$[p v v]=29.0$	

The sum of the squares of the weighted residuals has been reduced only from 33.6 to 29.0, showing that the preliminary elements were bettered very little by the least square solution. The probable error of a single position is ± 0.62 km. That for a single plate is slightly larger than ± 0.64 km. The value for $[p v v]$ given above is that derived from the forty positions used, seven of which were the mean of two plates, and one of three plates. The value of $[p v v]$ for the forty-eight plates taken independently is 33.4.

The solution is satisfactory, as may be seen from the following table. The residuals given by these elements are tabulated, and likewise a comparison of the differences produced by the changes

in the elements and those secured by direct substitution of the values of the unknowns in the equations of condition.

No.	O.–C.	Eph.–Equat.	No.	O.–C.	Eph.–Equat.
1......	–0.11	–0.04	21......	–0.75	–0.01
2......	–0.69	–0.06	22......	–1.15	0.00
3......	–0.12	+0.04	23......	+1.15	+0.02
4......	–0.21	–0.05	24......	–0.28	+0.02
5......	+1.33	–0.01	25......	+0.59	–0.03
6......	+0.23	0.00	26......	+0.24	–0.02
7......	–0.41	0.00	27......	–0.40	–0.07
8......	–1.60	–0.01	28......	–1.24	0.00
9......	+0.30	0.00	29......	0.00	+0.07
10......	+0.25	0.00	30......	–0.93	+0.01
11......	–0.12	–0.02	31......	+1.54	+0.01
12......	+0.80	–0.01	32......	–0.47	–0.01
13......	–0.12	+0.01	33......	–1.14	0.00
14......	+1.56	+0.02	34......	–1.18	–0.01
15......	+1.28	0.00	35......	+0.87	–0.06
16......	+1.39	–0.01	36......	+0.24	0.00
17......	–0.21	0.00	37......	–0.94	0.00
18......	–0.88	+0.03	38......	+0.04	0.00
19......	–1.69	–0.01	39......	+0.03	0.00
20......	+0.47	+0.01	40......	+0.62	0.00

In Fig. 3 I have plotted the velocity-curve of α_2 *Geminorum*, and the separate observations. The radius of the small circles represents the computed probable error of a plate, and the dotted line the velocity of the center of mass of the system.

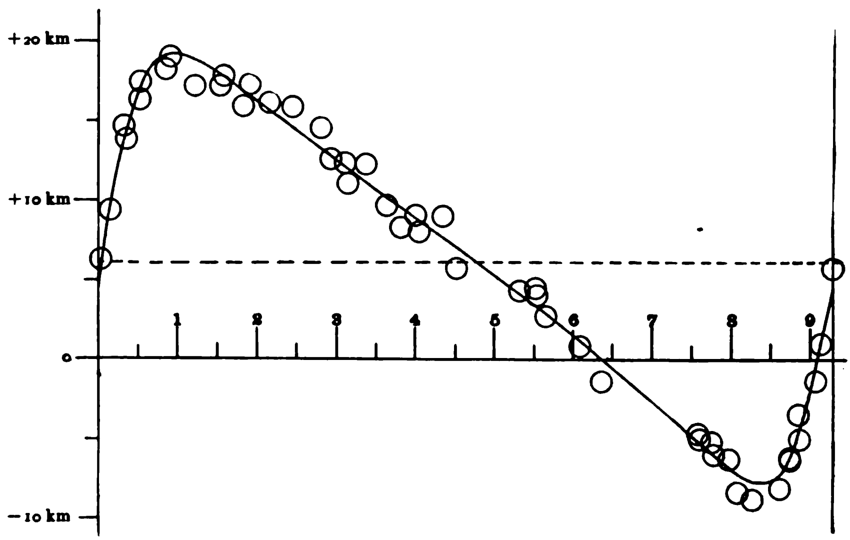


FIG. 3.—Velocity-Curve of α_2 *Geminorum*

THE VISUAL SYSTEM

The hope may naturally be entertained that a combination of spectrographic and visual results will eventually give a fairly accurate value of the parallax, masses, and the other physical constants of this unique quadruple system. Unfortunately the elements of the visual orbit are so indeterminate that no conclusion can be reached at present. Many orbits have been computed. An idea of their wide variation may be gathered from the following list of orbits given by Burnham in his *Catalogue of Double Stars*, advance proof-sheets of which were kindly sent me by the author. The date in the first column represents the last measures used in the respective determinations.

1831..........	Herschel	252.66 years	*Mem. R. A. S.*, **5**, 196, 1832
1841..........	Mädler	232.12	*A. N.*, **19**, 349, 1842
1845..........	Hind	632.27	*A. N.*, **23**, 377, 1846
1847..........	Mädler	519.77	*F. S.* **1**, 233.
1846..........	Jacob	653.1	*Mem. R. A. S.*, **16**, 321, 1847
1856..........	Thiele	996.85	*A. N.*, **52**, 39, 1860
1875..........	Wilson	982.9	*Handbook of Double Stars*
1877..........	Doberck	1001.21	*A. N.*, **91**, 119, 1878
1878..........	Thiele	720.	"*Castor*," Copenhagen, 1879
1889..........	Mann	265.7	*Sid. Mess.*, **9**, 385, 1890
1896..........	Burnham	Indeterminate	*Pop. Astr.*, **4**, 286, 1896
1898..........	Doberck	318.23	*A. N.*, **147**, 337, 1898
1904..........	Doberck	268.16 346.82 501.08	*A. N.*, **166**, 145, 1902

Burnham (reference above) considers that the problem of finding the elements is absolutely indeterminate at present, and likely to remain so for a century or so longer. Doberck (reference above) in his last paper gives three orbits of which he considers the one of period 347 years as the most probable, and there expresses the hope that the measures of the next twenty years may lead to a more accurate knowledge of the elements.

The relative velocity of the two components, as derived from the present discussion, is 7.14 km $\pm$ 0.23 km. Assuming Doberck's elements with period of 347 years, this would give a parallax of $0\overset{''}{.}05$. On this assumption as pointed out by Miss Clerke,[1] the total mass of the system would be 12.7 times that of the Sun. These results must be considered as extremely uncertain.

[1] *The Observatory*, **28**, 209, 1905.

Attention may be called to one or two other points of interest in the system. Assuming for each spectroscopic system an inclination of 63°, the same as that given by Doberck for the visual system, the semi-major axes of the two systems are

α_1 *Geminorum*, $a = 1{,}435{,}000$ km
α_2 *Geminorum*, $a = 1{,}667{,}000$ km

These values are admittedly mere hypotheses, but they convey an idea of the size of the systems and emphasize the fact that they are probably of the same order of magnitude. The assumption that the inclination of the orbital plane of each of the two systems is roughly that of the main system is not unreasonable.

We have then, in *Castor*, two systems whose orbital dimensions are probably of the same order of magnitude. The brighter component has, however, the very great eccentricity of 1.50, while the fainter pair revolve in orbits which are practically circles (eccentricity = 0.01). This extraordinary difference seems, by the generally accepted theories of stellar evolution, to indicate that the brighter component is the older, and that the fainter is, spectroscopically speaking, a binary of relatively recent origin. α_2 has already approximated to the eccentricity of the main system of dimensions, enormously greater, while its own major axis is probably not much greater than that of its companion system, still almost circular. On the other hand, the mass of the fainter component should be about six times that of the brighter one.

The effect of tidal action on a system so eccentric as that of α_2 must be enormous where at periastron the stars are but one-third their apastron distance apart. Such an eccentricity, in fact, has generally been found only in those spectroscopic binaries which also show variability in their light. The question naturally arises whether any such phenomenon exists in α_2. A series of observations was accordingly made with the smaller of the two Bruce double-image photometers belonging to the Lick Observatory, attached to the twelve-inch equatorial.[1] Five or six independent settings were made in each of the four positions of the Nicol prism, and from forty to sixty separate settings constitute an observation.

[1] A description of this type of instrument is given in the *Annals of the Harvard College Observatory*, 11, I, 105, 1879.

In each case the brightness of α_2 was compared with that of α_1, a method of procedure for which the double-image polarizing photometer is particularly adapted. In the reductions the magnitude of α_1 was assumed to be 3.70. Below are given the results of these observations; and I have prefixed for the sake of completeness, the Harvard observations of the same pair (*loc. cit.*).

PHOTOMETRIC OBSERVATIONS OF α_2 *GEMINORUM*

Date G. M. T.	Julian Day	Magn. α_2	R	Notes
HARVARD OBSERVATIONS—				
1878, February 15ᵈ 13ʰ.8....	2407031.565	2.79	+0.09	
13.9....	.577	2.66	+0.22	
16 11.6....	32.483	3.18	−0.30	
11.7....	.487	3.32	−0.44	
11.8....	.492	3.11	−0.23	
11.8....	.493	3.04	−0.16	
11.9....	.496	2.61	+0.27	
11.9....	.496	2.71	+0.17	
18 10.6....	34.441	2.66	+0.22	
10.6....	.441	2.72	+0.16	
	Mean	2.88		
LICK OBSERVATIONS—				
1905, January 16ᵈ 21ʰ 5ᵐ	2416862.879	2.73	+0.01	
26 18 22	72.765	2.72	+0.02	
27 14 17	73.595	2.79	−0.05	
27 22 26	73.935	2.58	+0.16	
28 14 29	74.604	2.75	−0.01	Seeing poor
February 7 15 8	84.626	2.66	+0.08	" "
8 14 49	85.617	2.71	+0.03	
12 14 35	89.608	2.52	+0.22	" "
12 22 6	89.921	2.84	−0.10	
13 14 57	90.623	2.71	+0.03	
23 14 53	6900.619	2.80	−0.06	
27 14 56	4.622	2.95	−0.21	
28 14 38	5.610	2.84	−0.10	
March 1 14 48	6.607	2.71	+0.03	
6 14 46	11.615	2.73	+0.01	
8 14 59	13.624	.88	−0.14	
	Mean	2.74		

No marked variation of regular period can be deduced from these observations. Such a variation, if it exists at all, is evidently small.

No irregularities have been detected in the velocity-curve of the spectrographic orbit.

PACIFIC MAIL STEAMER "SAN JUAN,"
Panama, January 24, 1906.

ON REFLECTING TELESCOPES OF RELATIVELY SHORT FOCUS[1]

By H. C. VOGEL

Just as, since the earliest days, there has existed a sort of competition between the refractor and the reflector, and a new success in one field has been soon equaled in the other, so also in recent times, after what is probably the acme of perfection in the production of great refractors had been attained a decade ago, the improvement of reflecting telescopes was undertaken, with great success, and today refractors and reflectors rank as of equal value. It is unlikely that very important improvements are to be expected in either of these so different instruments, and therefore we are rather compelled to assign to each of them a field of work for which it is particularly adapted. Thus it is likely that refractors of long focus will receive the preference when the largest usable field of view is in question. Refractors having objectives composed of more than two lenses, which, in consequence of the relatively short focus which can be given them, are particularly adapted for photographing large regions of the heavens and extensive masses of nebulæ, will find continued use in the execution of surveys like the *Durchmusterung*, and for finding comets and small planets. *Per contra*, reflecting telescopes have at present attained an immense advantage for the observation of nebulæ and star clusters of small extent, and they will doubtless permanently retain this advantage, inasmuch as it is based upon the characteristic properties of the mirror.

The well-known Ring Nebula of *Lyra* may serve here as an example. In a large refractor it appears as an elliptical ring, and one is easily struck by the unequal distribution of the brightness and unequal sharpness of the boundary, particularly at the ends of the major axis of the ellipse. An observer with a particularly good eye also gets the occasional impression of some brighter stellar points in the ring, and possibly of a small star at the center of the

[1] Paper presented to the *Kgl. Akademie der Wissenschaften*, Berlin, March 15, 1906. *Sitzungsberichte*, 1906, No. 14.

nebula, but he cannot retain these details in his vision with certainty. A photograph taken with one or two hours' exposure with a refractor having an objective corrected for the chemically active rays gives a better result. A fairly bright central star can be recognized in the interior of the nebula, and has a faint and somewhat diffuse companion.

The shadings in the ring of the nebula are very clearly perceptible. But on a photograph taken with one of the recent reflectors an exposure of only ten minutes yields an overexposed image of the ring.

The *Orion* nebula may be cited as a further example. The delicate details in the outlying portions of this nebula, which can just barely be seen by direct observation with a large telescope, but which cannot be perceived with enough certainty to permit a drawing to be made, can indeed be photographed with the refractor; but only with an exposure time in which a reflector of comparable size with the refractor would depict the nebula as a closed and almost circular mass.

This condition of affairs is particularly occasioned by the fact that in the focal image of the mirror all the colors are perfectly united, while the achromatism of a telescope with an objective of two lenses always leaves much to be desired; and since the diameters of the circles of chromatic aberration increase with the focal length of the refractor, the errors due to the imperfect achromatism soon exceed all the other errors of the objective. This defect of the refractor is especially conspicuous for nebulæ yielding the typical nebular spectrum, like the two which I have just cited as examples. I would here point out especially that it may happen that the pictures taken with a reflector appear differently from those with a refractor, if the ultra-violet rays of the light from a nebula having a discontinuous spectrum are more or less lost by absorption in the glass of the objective. This is particularly conspicuous if the distribution of intensity of the spectral lines is different in the different parts of one and the same object, as was proven to be the case for the *Orion* nebula by Mitchell at the Yerkes Observatory and by Hartmann at the Potsdam Observatory. In some parts of the nebula the principal nebular line in the green is exceedingly weak, while the ultra-violet line at λ 3727 is relatively strong throughout the whole

nebula, whence may be explained the differences which may be so readily noticed between photographs taken with a refractor and a reflector. It is to be further noted, and to be regarded as a disadvantage to refractors of long focus, that the difficulties are met with as a result of a defective achromatism in direct observations of gaseous nebulæ and neighboring stars. The maximum intensity in the continuous spectrum of a star lies between λ 560 and λ 570 $\mu\mu$, while in the nebular spectrum the brightest lines have wave-lengths λ 501, λ 496, and λ 486 $\mu\mu$. In a telescope with a focal length up to about 4 meters, the differences of the points where these wavelengths unite can hardly amount to 1 mm, measured along the optical axis, but with greater focal length they increase to several millimeters, and the eye is then not able to so accommodate itself that the stars and nebula will appear simultaneously sharp.

The astonishing advances which have recently been made with the aid of reflecting telescopes in our knowledge of the nebulæ depend in the first instance on the application of photography. We may say that it has opened a new era for this so interesting branch ot science. Objects which formerly were visible only with the mosf powerful instruments are readily photographed with small reflectors and the pictures give a richness of detail which could hardly be suspected in direct observations.

Further success is attained by the efforts to make the surface of the mirrors more perfect, and to give them the form of a paraboloid of revolution instead of a sphere. In this way the rays are united as perfectly as possible, at least in the optical axis, and in its neighborhood a better union of the rays is effected than with a spherical surface, from which an image free from error cannot be obtained even in the axis itself, on account of the spherical aberration. We are also thus put in the position for the first time of increasing the ratio of aperture to focal length, and thus of enormously increasing the intensity of the images both of extended celestial objects and of point-like stars (in the case of the latter particularly by diminishing the effect of the unsteadiness of the air). While the old reflectors of Herschel, Lord Rosse, Lassell, Draper, and others did not exceed the angular aperture of 1:9, we meet with the following values of this ratio in recent instruments:

		Aperture	Focal Length
1:6	Paris	119 cm	7.1 m
1:5.8	Lick Observatory (Crossley Reflector)	91	5.3
1:5.4	Common	152	8.2
1:4.9	Roberts	51	2.5
1:4	Yerkes Observatory	60	2.4
1:3.7	Schaeberle	30	1.1
1:3	Meudon	100	3.0
1:2.2	Common	52	1.1
1:1.54	Schaeberle	33	0.51

With the increase of perfection in the construction of mirrors, attention has also been given to the errors which are attached to them fundamentally, and these have been exhaustively investigated. I cite here the most important papers referring to the subject in so far as they are known to me,[1] and I would especially call attention to two very interesting papers by Schwarzschild, which appeared last year under the title "Untersuchungen zur geometrischen Optik."[2] The conditions for reflecting telescopes are explained in a very clear, and, by the use of the notion of Bruns' "Eikonal," in a highly elegant, manner. Schwarzschild's investigations in the second part of his paper have indeed led to the view that it may be possible by the use of two mirrors to produce an image perfect over a diameter of field of several degrees. The practical execution of his

[1] *Monthly Notices of the R. A. S.:* **47**, 244, 1887: J. F. Tennant, "Notes on Reflecting Telescopes." **47**, 394, 1887: McLaren, "On the Images Formed by Reflecting Mirrors, and Their Aberration." **62**, 345, 1897: H. C. Plummer, "On the Images Formed by a Parabolic Mirror."

Astronomical Journal: **16**, 25, 1896: J. M. Schaeberle, "Derivation of Fundamental Formulas for the Cassegrain (and Gregory) Telescopes." **18**, 35, 1897: J. M. Schaeberle, "On a Fundamental Optical Defect in the Images Formed by a Parabolic Reflector." **18**, 89, 1897: C. L. Poor, "The Aberration of Parabolic Mirrors." **19**, 17, 1898: J. M. Schaeberle, "General Theory of the Aberration in the Focal Plane of a Parabolic Mirror."

Astrophysical Journal: **7**, 114, 1898: C. L. Poor, "The Aberration of Parabolic Mirrors." **7**, 362, 1898: C. W. Crockett, "The Parabolic Mirror." **12**, 219, 1900: S. C. Reese, "Field of the Reflecting Telescope."

Popular Astronomy: **5**, 518, 1898: F. L. O. Wadsworth, "A Note on a New Form of Mirror for a Reflecting Telescope." **6**, 33, 1898: J. M. Schaeberle, "On the Definition and Intensity of a Star's Image in the Field of View of a Parabolic Reflecting Telescope." **6**, 39, 1898: J. M. Schaeberle, "On the Aberration of Parabolic Mirrors."

[2] *Astron. Mitteilungen der Königl. Sternwarte zu Göttingen,* Teile 9 und 10.

suggestions would, according to my experience, doubtless meet with some very grave mechanical and technical difficulties. The triumph of obtaining a fairly large aplanatic image in a telescope of large angular aperture (to which these investigations particularly apply), having the other good qualities of reflector images, would be, however, of such conspicuous significance that it would be worth the expenditure of a great deal of pains. It is true that a quarter of the whole light would be lost by the obscuration of the principal mirror by the second mirror, to which in the example given in the paper a diameter of half that of the large mirror was assigned. The difficulties which I fear in the execution of the plan do not lie in the production of the mirror, but essentially in the rigid connection of the two mirrors, and in their fine adjustment with respect to each other and to the photographic plate, which is troublesome even in the simplest form of reflecting instrument—a mirror with a photographic plate at the focus. This troublesome adjustment would have to be made often, inasmuch as glass mirrors with a silvered surface are at present in general use, and the silver surface has to be renewed at short intervals.

At present we must content ourselves with the use of mirrors having large angular aperture, with all the errors that attach to them. As already indicated, these consist in the fact that in a perfectly parabolic mirror an accurately round image of a star is obtained only in the optical axis, while outside of the axis we can only obtain images of a star which are affected by a coma. The image formed in a plane at right angles to the optical axis of the mirror (as on a photographic plate) assumes the shape of a pear, which becomes the more distinct the farther the star is situated from the axis. The distribution of light in these images is unequal, with the greatest intensity at the point. It is not possible to obtain a round image of a star situated away from the center by any alteration of the focus of the plate. It is thus not possible to make a sort of compromise in respect to the focus, as can be done with the compound objective, in order to get the smallest amount of poor definiton extending uniformly over a larger area.

The image curvature, which also occurs as an error in mirrors, produces a further deformation of the images which are not situ-

ated in the axis, but this does not equal the effect of the coma until the distance from the axis is large.

The following table, which I have taken from Schwarzchild's paper (Part 2, p. 11), shows how large these errors become for different ratios of aperture and for different extents of the field of view.

Ratio of Aperture	Diameter of Field of View	Spreading from Image Curvature	Spreading from Coma
1:10	½°	0'.4	1'.7
	1	1.6	3.4
	2	6.3	6.8
	4	25.2	13.6
1:3	½	1.3	18.7
	1	5.0	37.4
	2	20.0	74.9
	4	83.8	149.8

This summary indicates that the usable field of view of telescopes with an angular aperture of 1:3 will have a diameter of from 30′ to 40′ only. But when we reflect that the dimensions of a very great number of nebulæ do not exceed 20′, we conclude that a rich field of work is assured for a mirror of the above-named ratio. It is here to be assumed that the perfection of the mirror will be such that it will be possible to obtain the images small in respect to the aperture (which would again furnish the advantage of great light-power), so that they would be comparable in richness of detail with the plates taken with reflectors of greater focal length. I would further call attention to the fact that matters may be helped for an object of larger extent by photographing different parts of it separately, and that, when the brightness of the object is sufficient, a usable image of greater extent can always be obtained by reducing the aperture of the mirror. The size of the usable field of view, moreover, increases with great rapidity with the decrease of the angular aperture.

A reflecting telescope of large angular aperture offers decided advantages for spectrographic observations of nebulæ and faint stars, as may be easily seen. The intensity of the unit of surface increases in proportion to the square of the diminution of the extent of the images of nebulæ. Moreover, since the star disks produced

on the photographic plate by the unsteadiness of the air are smaller for a short focus than for a long focus, all the faint stars will be obtained on the plates for instruments of short focus, which, for an instrument of longer focus, could not affect the bromide of silver on account of the too feeble intensity of the star disks caused by the unsteadiness, which are also enlarged as a consequence of the longer focus. These considerations led Professor Scheiner a few years ago to begin experiments in this direction at the Astrophysical Observatory with a provisionally constructed instrument (a mirror of 32 cm diameter and of 96 cm focus). But as the mirror was spherical, and the star disks as a consequence necessarily had considerable dimensions even in the optical axis itself, the results in no wise corresponded to the expectations.

The highly interesting discovery a few years ago of a nebula about the fading *Nova Persei*, which was of much importance for the solution of the problem of the nature of temporary stars, spurred me on to have renewed experiments made with mirrors of short focus at this observatory, in order that thus in general the program of the observatory might be developed in this direction, and in particular that important observations of that sort for which a reflecting telescope appeared particularly suited, could be made here, having previously necessarily been left for observers abroad.[1] In the year 1904 I received from Steinheil, of Munich, a mirror of 30 cm diameter, of which, however, only a diameter of 24 cm had been figured by the optician. The focal length was 90 cm, and accordingly the ratio was 1:3.8. Dr. Eberhard made an investigation of the mirror by Hartmann's method of extra-focal plates, with the result following (p. 377).

Upon the conclusion of this investigation I had a solid mounting given to the mirror, particular weight being laid upon the stability and possibility of a fine adjustment of the plate with respect to the optical axis of the mirror. The mounting was constructed by O. Toepfer & Son, in Potsdam, according to the precise specifications

[1] Hitherto no reflecting telescope of short focus has been in use in Germany. The fact that Wolf, of Heidelberg, gave the name of the Bruce Telescope to the instrument given by Miss Bruce, with which he makes his beautiful plates of stars and nebulæ, has repeatedly led to the misunderstanding that this was a reflecting telescope.

of myself and Dr. Eberhard. After Dr. Eberhard, in conjunction with Dr. Ludendorff, had in a most careful manner effected the somewhat troublesome adjustment of the telescope, which was used in connection with the oft-mentioned refractor of 32.5 cm aperture, excellent plates were obtained by those gentlemen of the

Radius of Zone	Deviation Measured in the Axis
54 mm	+0.28 mm
69	+0.13
84	+0.09
100	−0.14
114	−0.40

best-known objects (nebula in *Orion*, Spiral nebula in *Canes Venatici*, the Dumbbell nebula, etc.) in the winter of 1904–5, and these furnished a proof that very useful results could be obtained even with an instrument of such small dimensions.

Meanwhile I received from Mr. B. Schmidt, of Mittweida (Saxony), of whose special accomplishments in the production of paraboic surfaces I had heard, a mirror of 40 cm diameter and 2 meters focus, for examination and trial. The investigation of this mirror by Dr. Eberhard disclosed so great perfection in the union of the rays coming from different zones of the mirror that I inquired of Mr. Schmidt whether he would be willing to undertake the very laborious work of producing a mirror having a ratio of aperture to focal length of about 1:2.5. After his assent, we agreed together that the mirror should have a usable aperture of 40 cm and a focal length of 93 cm, and that the deviations in the union of the rays at the focus should not exceed ±0.1 mm, measured along the optical axis. It will appear from what follows how Mr. Schmidt fulfilled these conditions, and I would further remark that the time of delivery of only three months after the definitive order was strictly complied with.

I have for the time been obliged to abandon my original desire of giving this mirror a mounting of its own, inasmuch as its equipment in an adequate manner would have involved large expense and, still worse, a long time, so that my wish to test the telescope as soon as possible by celestial observations would have had to be

postponed for at least a year, as with the new mounting a suitable place for observing would also need to be provided. Accordingly, I had this telescope mounted by Messrs. Toepfer & Son in a similar manner to the mirror of 30 cm diameter already mentioned, and attached the reflecting telescope rigidly to the tube of the small photographic refractor. To avoid overloading this instrument, the optical portion and the eyepiece attachment of the photographic tube were removed. The visual guiding telescope of the refractor of 23 cm aperture has served as guiding telescope for the plates taken with the mirror. The weight was further relieved by the use of nickel-aluminum for the cell of the mirror and for the supports of the plate-holder. The mirror has a thickness of 58 mm and a diameter of 44 cm with a usable surface of 41 cm, and the focal length is 92.7 cm. The tube, made of thin sheet steel, has a diameter of 47.8 cm, and to one of its ends the mirror is attached to a very solid cell resting on a ring of 30 cm diameter; at the other end the steel tube is strengthened by a ring having an opening of 45.8 cm. To this are attached three bars of 8 mm thickness which support the circular section of 90 mm diameter which carries the plate-holder. The arrangement for the precise focusing of the plate, as well as for inclining it to the optical axis and for giving the plate a slight lateral displacement, has been adopted from the mounting of the 30-cm reflector, on which it has proved very satisfactory. The size of the plate is 5×5 cm. The scale with vernier which can be read by a microscope makes it possible to set the plate at the focus with an accuracy of 0.05 mm. A setting incorrect by only 0.1 mm is enough to appreciably impair the image. Up to the present an effect of the temperature on the focal setting has not been demonstrable between the temperatures $+5^\circ$ and $-6^\circ\!.5$ C. Since Drs. Eberhard and Ludendorff completed a careful adjustment of the telescope, at the end of October 1905, photographs of celestial objects have been made by them on every favorable occasion, although the number of plates is unfortunately not very large on account of the exceptionally bad weather during this past winter. Nevertheless, I believe I am justified in declaring that I regard our instrument as one of the most perfect of its kind in existence at present.

After these general considerations I now take up the details of the Schmidt reflector having the ratio of aperture to focal length of 1:2.26.

1. *The investigations of the zones* of the mirror from measurements by Dr. Eberhard (E.) and B. Schmidt (Sch.) gave the following deviations measured in the optical axis, for the points of union of the rays.

Radius of Zone	Deviation		Radius of Zone	Deviation	
	E.	Sch.		E.	Sch.
40 mm	— mm	0.00 mm	147 mm	+0.01 mm	— mm
65	—	.00	150	—	−0.02
70	+0.01	—	160	—	− .03
80	+ .03	—	165	−.03	—
90	—	+.02	170	—	− .03
100	+ .03	—	180	—	− .04
110	—	+.03	185	−.10	—
115	+ .07	—	190	—	− .04
125	—	+.01	195	−.09	—
135	.00	—	200	—	− .01
140	—	−.005	205	—	+ .01

The values by Eberhard are somewhat larger than those of Schmidt, but the latter are the more trustworthy, since Eberhard's measures lie at the limit of what can be accomplished by the method of extra-focal images, while Schmidt could go farther with the observations of the interfering images in the focus. In both determinations the position and width of the zones was different, as may be seen from the summary, and this may not have been without effect on the result. The course of a curve drawn through the points of union determined by observation is very clearly seen in both series. If the center of the disk of the image is desired, the deviations measured in the axis are to be multiplied by the angular aperture of the zones under consideration. With the full aperture of the mirror values are derived for the maximum which are in good agreement with those obtained from direct measures of star-images.

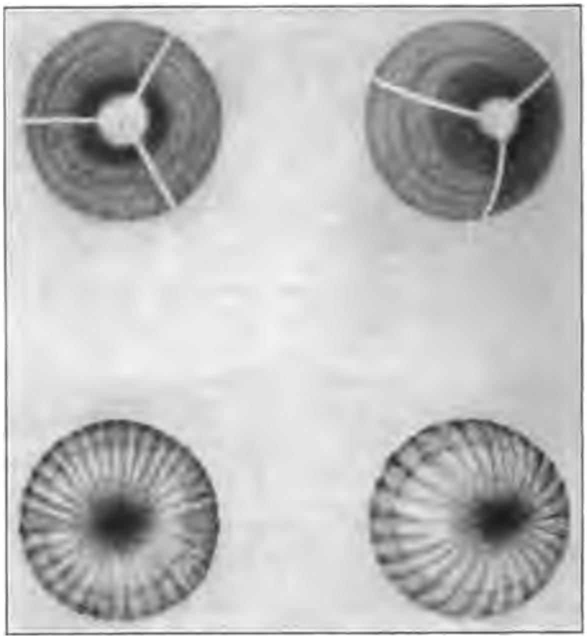
2. I have measured on different plates and on very many stars, and have found *the size of the smallest images* in the neighborhood of the axis to be 0.015 mm, corresponding to 3.″3; these points are not perfectly regular in shape, and are somewhat dull. The

diameter of the round and uniformly blackened star-images came out to be 0.03 mm or 7″.3.[1]

3. *Extra-focal images* taken with the full aperture of the mirror are seen under the microscope to be of great uniformity and allow us to infer from this uniformity of the distribution of light that the zonal errors are exceedingly small. It is further interesting to see

1

2



3

4

FIGS. 1–4

in them a shadow of the plate-support with its three bars. I regard this as an excellent criterion for the extraordinarily good quality of the mirror, for such an image can be formed only when the separate zones belong to one and the same paraboloid of rotation. If the axes of the separate zones do not precisely coincide, or if the parabola which corresponds to the sectional surface of the paraboloid in the axis does not run uniformly, but forms small waves,

[1] With a focal length of 92.7 cm the relation between the linear extent at the focus and the angular value is:

1 mm=3′.71=222″.5; 1′=0.27 mm.

the foci of the separate zones may indeed fall at the same distance from the vertex of the paraboloid (as indicated by the zonal test) without actually coinciding. They then lie in a surface beside each other, and in such a case the stars may appear drawn out at the focus (astigmatic error) or even round, but of greater extent and with more irregular boundaries than in a more perfect mirror. I believe that the accompanying figures, which I have made from extra-focal star plates, will be of interest for the possessors of reflecting telescopes. Fig. 1 is the extra-focal image of a star in the axis; Fig. 2, that of a star at some distance from the axis, both of these referring to the Schmidt mirror. Figs. 3 and 4 are extra-focal plates of stars in a less perfect mirror, in one case in the axis, and in the other at a slight distance therefrom.

4. *Coma.*—I thought it of interest to make some more accurate measurements on the images which are formed on the plate at the focus at different distances from the axis of the mirror when its full aperture was used, hence when the angular aperture is 1:2.26. For this purpose a plate was prepared on which δ *Orionis* was successively photographed in the axis and at equal distances of 10′ therefrom, with the uniform exposure time of one minute. On account of the richness of this region in the heavens, a large number of fainter stars are contained on the plate, so that numerous measurements could be made on these, the results of which I communicate here.

Distance from the Axis	Length of the Coma	
0′	0.000 mm	0″.0
10	0.040	8.9
20	0.113	25.1
30	0.188	41.8
40	0.278	61.9
50	0.375	83.4
60	0.483	107.5
70	0.595	132.4

The measures were made on seven pictures of δ *Orionis* up to a distance of 60′ from the axis, as well as on twenty-three images of fainter stars to a distance of 67′. The results of these can be very well represented by a curve from which the value for the linear

extent of the star-image may be taken for distances of 10′, 20′, etc., from the axis, and are given in the table above.

I have also determined, from measurements on several stars on two plates, the size of the coma at a distance of 56′ from the axis, with the mirror diaphragmed down to 24 cm, corresponding to an angular aperture of 1:3.86. I found the linear extent of the images to be 0.135 mm or 30″. A comparison of these measures with the data from Schwarzchild's table, already cited, indicates that the spreading turns out smaller than was to be expected from the computation.

I have further determined from numerous star-images the ratio between linear extent and greatest width. It is very accurately 3:2. The angles formed at the vertex of the star-images affected by coma came out to be exactly 60°, and the distance of the perpendiculars on the axis of length of the figure, which corresponds to the greatest width, I found to be two-thirds of the axis of length from the vertex. If circles are drawn in an angle of 60° in such a way that their circumferences touch the sides of the angle (Fig. 5), the precise figure of the distortion images of the stars outside the axis will be obtained. I have sought to represent the distribution of light on them in Fig. 6. With a sufficient intensity of light the whole figure will become so black on the negative that no shading can be perceived. A slight narrowing before the point is reached is more noticeable than in the image of fainter stars, which probably has its cause in the irradiation of the most intense place in the photographic film at the vertex of the figure. In the case of very faint stars the figure is not closed, and one can only recognize an angle, the sides of which appear without any boundary inward but bounded by perfectly straight lines outward. The arc indicated in Fig. 6 often appears, and not seldom are the star-images provided with a narrow lengthwise streak—the shadow of one of the bars which support the plate-holder, if the linear extent of the image accidentally coincides with the direction of one of the bars.

5. *Performance of the Schmidt mirror in comparison with other instruments.*—Only a small amount of data is available as to the performance of reflectors with very large angular apertures. Photographs of several of the better-known nebulæ were made by M.

Rabourdin with the reflector of the Observatory at Meudon, 1 m: 3 m, and M. Janssen has reported on these in *Comptes Rendus*, **126** and **128**. From the descriptions, which do not go farther into detail, the conclusion cannot be drawn that the instrument possesses remarkable properties, and must be regarded as an improvement as compared with other instruments. *Per contra*, the few pictures in *Comptes Rendus*, **128**, which, it is true, were not well reproduced, only testify that either the focusing of the plate was insufficiently accurate, or that the mirror is not free from errors. In particular, the stars do not appear as disks in the pictures of

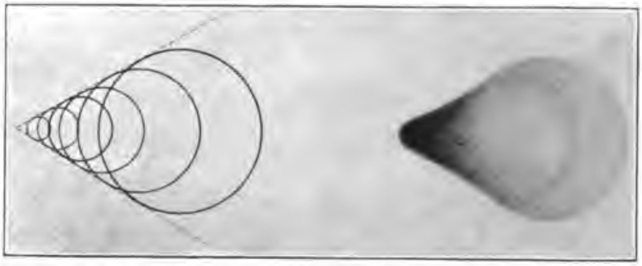


FIG. 5 FIG. 6

the cluster in *Hercules* which were taken with different exposures, but as irregular elliptical rings with or without a stellar nucleus.

Schaeberle's highly interesting attempt to produce a mirror with an angular aperture of 1:1.54 seems to have been a success,[1] but, from the small number of plates hitherto described, its advantages cannot, in my opinion, be regarded as sufficiently well established. The paper cited is accompanied by a photographic reproduction of the Ring nebula in *Lyra*, which, however, shows nothing striking. The too great enlargement (75 times) of the photograph, as sent by the author for publication, was unfortunately doubled by the editor, so that, in consequence of the very pronounced silver-grain, almost every detail is lost, as well as any chance to get an idea as to the quality of the definition of the mirror. Schaeberle in two other papers has communicated observations on the Ring

[1] *Astronomical Journal*, No. 539, **23**, 109–113, 1903: "On the Photographic Efficiency of a 13-Inch Reflector of 20 Inches Focus."

nebula and on the Dumbbell nebula.[1] Here, too, the images were greatly enlarged, 22 and 15 times respectively. From these photographs I have not been able to convince myself of the presence of a spiral structure which was said to appear with long exposure in the exterior parts of this nebula, as well as in the nebulæ in the neighborhood of γ *Cassiopeiae* and in the grouping of the stars in the cluster of *Hercules.*

In consequence of the unfavorable weather in the past autumn, it was unfortunately not possible to obtain here photographs of the Ring nebula in *Lyra* and of the Dumbbell nebula. The nebulæ of γ *Cassiopeiae* appear on our plates in complete agreement with those on the photographs of Roberts.

Schaeberle's remarks as to the astonishing light-power of his instrument is respect to depicting faint stars is, however, confirmed by the observations made here, as I shall show farther on. Since nothing further is known to me as to mirrors with relatively very short focal length, it only remains to compare the results thus far obtained at Potsdam with those secured by Roberts[2] with a mirror of 51 cm diameter and a ratio of 1:5, at his private observatory, and with those obtained at the Lick Observatory by Keeler with the Crossley reflector of 91 cm diameter and a ratio of 1:6.

The Schmidt 41-cm mirror with full aperture shows with 2 minutes' exposure the brightest portion of the nebulæ in the *Pleiades.* With an exposure of 30 minutes all the details appear which were obtained on Keeler's plates with the Crossley reflector in 4 hours, and something more than the 4 hour exposure of Roberts[3] yielded. The usable field of view with the 41-cm reflector at full aperture is too small to represent the *Pleiades* on one plate, as is possible with telescopes of less angular aperture.

The nebulæ about γ *Cassipeiae* appear as distinctly in 40 minutes with full aperture as on the plates taken by Roberts in 90 minutes on October 25, 1895 (Vol. **2**, p. 159, Plate 25, of Roberts.)

[1] *Astronomical Journal,* No. 547, **23**, 181–182, 1903. "The Ring Nebula in *Lyra,* and the Dumbbell Nebula in *Vulpecula,* as Great Spirals." No. 552 (**23**, 225, 1903), "On the Spiral Character of the Nebulosities Surrounding γ *Cassiopeiae.*"

[2] *Selections of Photographs of Stars, Star Clusters and Nebulae,* Vol. II, p. 159, Plate 25.

[3] *Loc. cit.,* Vol. I, p. 47, Plate 11.

Hind's variable nebula near *T Tauri*, which Keeler[1] obtained with the Crossley reflector by an exposure of 4 hours, can be distinctly seen on a plate taken in 2 hours with the Schmidt reflector.

An exposure of 2 hours on the Crab nebula (*N. G. C.* 1952, *h* 357) surpasses that obtained by Roberts[2] in 3 hours. The photographs do not resemble the fantastic picture of the nebula drawn by Lord Rosse from the appearance in the great reflector (of 183 cm aperture), from which the nebula received its name. The brighter part of the nebula has the form of a rhomb. Its exterior boundary is indeed irregular and shows at one place a very marked indentation, but the outlying portions cannot be detected in the manner of the above-mentioned drawing. The numerous stars in the neighborhood of the nebula shown by Roberts' plate can all be found on our photograph, on which a few more are present; the extent of the nebula is also somewhat greater than on Roberts' plate. The very interesting nebulæ near *ζ Orionis* (*N. G. C.* 2023 and 2024) are visible on a plate exposed only 10 minutes, as is even the faint streak of nebula which is at one place very sharply bounded by a straight line and has a circular sharply defined indentation. I have at hand only a beautiful picture of this nebula by Herr von Gothard, which was obtained with a reflecting telescope of small angular aperture in about 8 hours. The accompanying sketch (Fig. 7) was made by Dr. Münch from a 2 hours' exposure with the Schmidt mirror when diaphragmed down to 31 cm. The faintest stars are included only in the neighborhood of the nebulous matter.[3]

The aperture of the 41-cm mirror was cut down to 24 cm in order to obtain a larger field of view of different objects of large extent, thus giving an angular aperture of 1:3.86. After subtracting the area of the mirror shaded by the apparatus for supporting the plate, the diameter of the surface of the mirror actually used amounts to only 21.7 cm. All the details in the nebula of *Orion* exhibited by a plate of Roberts[4] with 3 hours and 25 minutes exposure, can

[1] *Monthly Notices*, **60**, 424, 1900. [2] *Loc. cit.*, Vol. 1, p. 53, Plate 14.

[3] The drawing and still better the original agrees well with the photograph by Roberts (*Astropyhsical Journal*, **17**, Plate IV), to which my attention was called during the printing of this paper. Roberts did not give any data as to the duration of exposure.

[4] *Loc. cit.*, Vol. I, p. 59, Plate 17.

be recognized on our exposure of 1 hour, and all the stars on Roberts' plate were also obtained. The central brighter parts of the nebula which were somewhat overexposed in 1 hour could be admirably

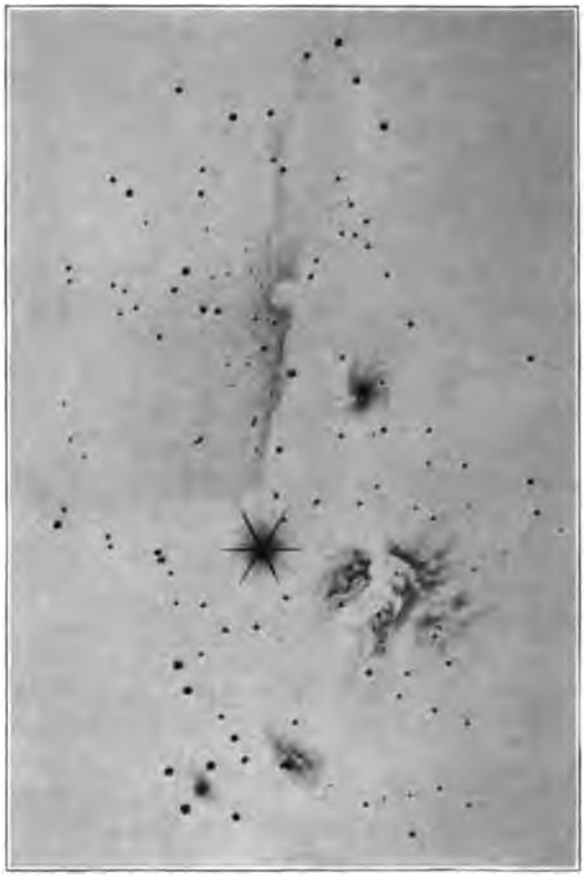


FIG. 7.—Nebulae near *ζ Orionis*

represented on more fine-grained and less sensitive plates with exposures of 10 and 30 minutes.

A very beautiful picture was obtained of the interesting spiral nebula *M* 33 *Trianguli* (*N. G. C.* 598, *h* 131) in a 2 hours' exposure, with an angular aperture of 1 : 3.86, but in consequence of its very small linear extent it does not fully equal in respect to the finest details

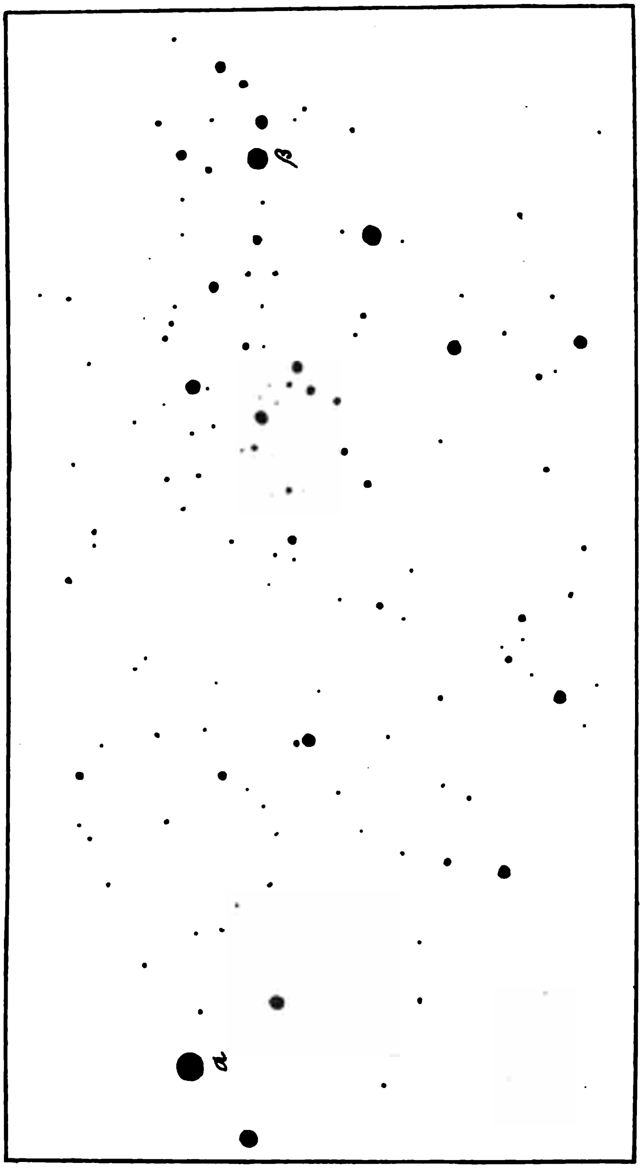


FIG. 8.—Region of numerous stars, 4^m following ε *Orionis*

α, 6.8 mag., *B.D.*, $-1°$: 1004. 1900.0: $5^h 35^m 46^s$; $-1° 10' 53''$.

β, 8.4 mag., *B.D.*, $-1°$: 990. 1900.0: 5 33 51 ; -1 13 37 .

the plate obtained with the Crossley reflector with 3½ hours' exposure, although it approaches it very closely. The Potsdam plate is not inferior to the photograph by Roberts with 2¼ hours' exposure (Plate 10, p. 65, Vol. 2).

On a plate of the cluster in *Hercules*, taken with the aperture cut down to 24 cm, as many stars were obtained in 5 minutes as on a plate of from 60 to 120 minutes taken with the 32.5-cm objective of the Potsdam photographic refractor.

A photograph of the extraordinarily rich region around γ *Cassiopeiae* shows, with 60 minutes' exposure, many more stars than appear on the reproduction given by Roberts (Plate 4, p. 33, Vol. 1) of his plate taken in 90 minutes on January 17, 1890. The nebulæ in the neighborhood of the star can be very distinctly seen, which were not visible on those plates of Roberts.

The following remarks may be added as to the light-power for depicting faint stars. Mr. R. H. Tucker[1] prepared at the Lick observatory small charts of different parts of the heavens, on which all stars which were even barely visible with a great refractor of 91.5 cm aperture under good atmospheric conditions are included. We have thus far been able to test only one of these charts (No. 3, of the region near ε *Orionis*), and we have obtained the satisfactory result that with an exposure of only 10 minutes at the full aperture of the Schmidt mirror, not only were all the faintest stars of magnitude 16 to 17 obtained which are visible in the powerful Lick telescope, but the number of the faint stars is decidedly larger, although at the time the silvering of the mirror, which often has to be renewed, had already suffered considerably.

On the basis of a measurement of the plates made by Drs. Eberhard and Ludendorff, Dr. Münch has prepared a chart in which all stars are entered which should be distinctly recognized as such. On this some inaccuracies in Tucker's drawing could be corrected, and I believe that the reproduction of this chart (Fig. 8) may be of interest. The chart extends in declination somewhat farther than Tucker's drawing, but in right ascension includes only about half as much as his. In equal regions of Tucker's drawing and of the photograph obtained here, he has forty-four stars fainter

[1] *Publications of the Astronomical Society of the Pacific*, **8**, 95, 1896.

than the twelfth magnitude, while the photograph shows 61 stars below this magnitude.

I hope that further interesting results may be brought to light with this beautiful mirror, particularly if we are successful in attaching a suitable spectrograph to the reflector. The prospect of this is indeed still somewhat remote, as the reflector must first receive a mounting of its own, so that a longer series of observations can be carried out without interruption, which is not possible in the present provisional attachment of the instrument to the photographic refractor. Furthermore, this admirable refractor can only be temporarily allowed to continue in this partially dismounted condition. The construction of the spectrograph with its optical parts of quartz is yet to be thought out and given practical form. Then a suitable observing-house is to be provided, which I am thinking of arranging in such a manner that it will be easily transportable, in the hope that this excellent little telescope may be set up in some more suitable place than in Germany, and particularly than in the damp region of Potsdam, in order that the telescope shall be fully utilized. But the first thing will be to raise the money for this very desirable expansion of the instrumental equipment of the observatory, which in any case promises a successful result.

Astrophysikalisches Observatorium,
Potsdam.

A LARGE QUARTZ SPECTROGRAPH

By PERCIVAL LEWIS

With the aid of a generous grant from the Carnegie Institution of Washington, the writer has been enabled to purchase two exceptionally large quartz prisms, with lenses of corresponding size, and the other materials for the construction of a powerful quartz spectrograph to be used for investigations of ultra-violet spectra. This instrument has been built from the writer's designs by Mr. W. R. Stamper, the mechanician of the Physics Department of the University of California. Much credit is due to him for his suggestions and skilful workmanship.

The prisms are of the Cornu type, each consisting of two half-prisms of 30° angle, of right and of left rotation respectively. Their height is 6.8 cm, and the length of face 9.2 cm. The crystal is perfectly clear and free from air-bubbles. The lenses are plano-convex, 9.2 cm in diameter, and of 1 m focal length for sodium light. They were made by A. Jobin, of Paris, who spent several months in the search for crystals of the requisite size and quality. The surfaces of the prisms are guaranteed accurately plane within one-fifth of a wave-length.

A view of the instrument is given in Fig. 2. The collimator tube, prism-box, and camera-box are in a vertical plane, to secure compactness, stability, and convenience of manipulation, the slit being horizontal. The supporting framework is of cast iron and brass, with tie-rods of iron to secure rigidity. The extreme height is 145 cm, but the collimator tube slopes downward at an angle of about 15°, so that the slit is about 105 cm above the floor, as shown in Fig. 2 by the meter rod leaning against the end of the collimator. This brings the slit into a convenient position with respect to a source of radiation placed on an ordinary laboratory table. The camera-box projects into a small cabinet protected by dark hangings, so that the film-holder may be loaded, placed in position, exposed, taken out, and the film developed without darkening the workroom.

The camera-box has a rigid framework of angle-iron, and is covered with sheet aluminum, blackened on the inside. Its axis is approximately at right angles to the collimator; but adjustment through several degrees is possible by rotating it about an axis *A* (Fig. 1) passing through the center of the prism-box. The latter has brass side-plates, built up on a cast brass bed, with a hinged top of sheet aluminum, which swings back to give access to the prisms. Each prism is mounted on a wooden block *B*, and fits snugly between two side boards of wood, with thin flanges on the lower side of each to keep the prisms from slipping out. There is no pressure whatever on the prisms. Each prism-holder is suspended on pivots *C* and *D* coinciding with the prolongations of the median lines of the prism-faces adjacent to the collimator and the camera lens respectively, these pivots being fixed to the prism-box in the case of the prism next the collimator, and to the prolongation of the sides of the camera-box in the case of the other prism. By this device the prisms are kept automatically with their effective apertures centrally situated with respect to the lenses. The adjacent angles of the prisms are only a few millimeters apart and in the line of the axis *A* on which the camera-box swings. The angular adjustment of the prisms is controlled by two screws *S* which pass up through the bed-plate and tilt the prism-holders about their axes. The lenses are fixed in position as near as possible to the prisms, and all focusing is done by displacing the slit or film-holder.

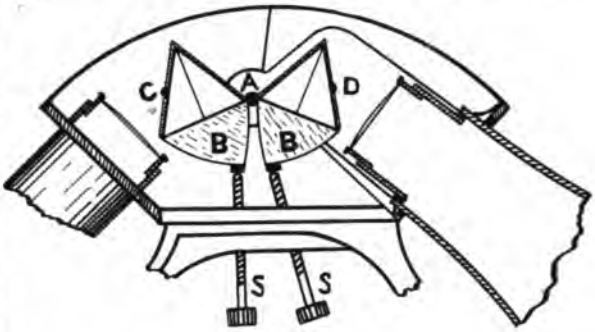


FIG. 1

The platform upon which the film-holder rests is accessible through a hinged door, which is shown open in Fig. 2. The distance of this platform from the camera lens is adjusted by a screw connected by a bevel gear with a crank behind the camera-box.

It can be set at any desired angle with the axis of the camera lens with the help of a divided circle on the outside, and clamped firmly in position. The film-holder is of wood, and is held accurately in place by two pins projecting upward from the platform, on or

FIG. 2

from which it can easily and quickly be set or removed. The upper surface of the holder, on which the film rests, is of sheet brass, its curvature being adjustable within limits by the screws which hold it against its wooden base. The film-holder may be moved parallel to itself, for the purpose of taking several exposures on the same film, by a screw operated by a crank in the rear. The curvature of the focal surface is so great with two prisms (the radius of curvature being only 60 cm) that glass plates cannot be used. So far ordinary Eastman films have been used, cut into strips about 4 cm wide and 40 cm long, but the intention is to use stiffer celluloid plates. These films are held firmly against the upper surface

of the holder by a spring brass frame having the same curvature as the latter and kept in place by hinge-pins at one end and a spring-clip at the other.

A long series of trials showed that the best results in dispersion and definition were obtained with equal focal distances of about 91 cm for slit and film-holder. This corresponds to adjustment for a parallel beam for about λ 2600, or about the middle of the spectrum. The prisms are set for minimum deviation for a wave-length of about 2400. As shown by V. Schumann,[1] better definition throughout the spectrum is gained by setting the prisms for minimum deviation of the shortest waves observed; but it was found inadvisable to do this with two thick prisms, because the less refrangible waves then traverse the prism at such a great angle with the optic axis that perceptible double refraction occurs. In cases when the angle of incidence was 57° or more the sodium lines were seen as distinctly separated plane-polarized doublets. With an angle of incidence of 53° or 54° this effect is not observed.

Both the curvature of the focal surface and its angle with the camera axis vary with the relative focal distances of slit and camera. With one prism the angle of the film-holder with the axis is only about 26°. With two prisms, however, this angle is increased to about 47°, so that the angle of incidence on the film is much diminished, with consequent great improvement in narrowness of lines and diminution of the distorting effect due to inequalities in the surface of the film.

A trial was made of the arrangement recommended by Hartmann,[2] a half-prism being placed directly in front of each lens, so that the light enters normally on the side opposite to the hypothenuse. The second prism was placed symmetrically between the two half-prisms. The arrangement was found to be unsatisfactory when used with two half-prisms and one double prism. The dispersion was only two-thirds as great as with the ordinary arrangement (as might have been predicted by calculation), and it was necessary to place the film-holder so obliquely to the incident light that broadening and irregularities of the lines became very pronounced. With

[1] *Wiener Berichte*, **102**, 664, 1893.

[2] *Zeitschrift für Instrumentenkunde*, **25**, 161, 1905.

the two half-prisms alone the results would probably have been better.

Photographs have been obtained giving good definition throughout the range between λ 2100 and λ 6000. The length of this spectrum is about 40 cm. The spherical aberration of the lenses manifested itself in a faint nimbus around the stronger lines, observable only after overexposure. Of course, only those lines due to pencils which are parallel or which traverse the prism at the angle of minimum deviation are strictly homocentric images of the slit; the other lines are focal-line images, endowed with the defects of these images, such as a slight dissymmetry or faint "wings" on one side. Such effects are noticeable, however, only above a wave-length of about 5000. The resolving power of the system is so great and the

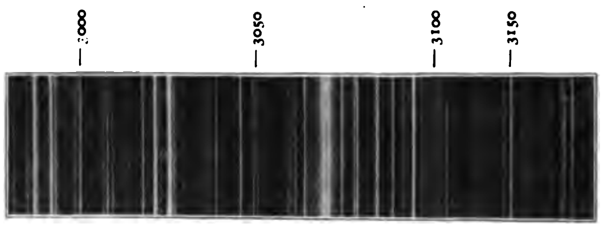


FIG. 3

lines so narrow, that these defects are evident only under a microscope even above λ 5500, and cannot seriously affect accuracy of measurement.

The details of the photographed spectra are so fine as to require magnification to bring them out. Fig. 3 is a fourfold enlargement of a small part of the bismuth and iron arc spectrum. The strong reversed line at the center is the bismuth line λ 3067.8. Although this region is at some distance from that in which the conditions for homocentricity exist (λλ 2400–2600), the lines are sharp and symmetrical. More than two hundred lines are distinctly to be seen with a microscope in this space of about 200 Ångström units. Many of the fine details are lost in the reproduction.

The dispersion in the visible spectrum is, of course, small, but in the extreme ultra-violet it exceeds that of a 15-foot grating. In the neighborhood of the D lines there are about 70 Ångström units

per millimeter; at λ 4500, about 30; at λ 3000, about 8; at λ 2700, about 5; at λ 2400, about 3; and at λ 2200, about 2. With a 15-foot grating the dispersion is about 3.7 units per millimeter in the first order.

This spectrograph also possesses great light-power, as compared with a grating. The arc spectrum of iron requires only 1 second of exposure for the ultra-violet, while for the grating half a minute or more is necessary. This instrument will, therefore, be very useful in the investigation of faint ultra-violet spectra.

Owing to the great thickness of the optical system, the absorption of the quartz becomes very noticeable at λ 2200. In using Hartmann's double-slit extra-focal method of focusing only one image of each line could be observed in this region. It was found that this image was due to the pencil passing through the thin edge of the prisms; that passing near their base was completely absorbed.

UNIVERSITY OF CALIFORNIA,
April 7, 1906.

OBJECTIVE-PRISM COMPARISON SPECTROGRAPH

By DE LISLE STEWART

The accompanying figures show an arrangement for utilizing objective-prisms for "line-of-sight" determinations. Two objectives L^1 and L^2, preferably of equal diameter and equal focal length, are mounted so that their optical axes make an angle of several degrees with each other, 15° in this case. Before each is placed an objective-prism P^1, P^2, of about 12° angle. The thick edges of these prisms face each other. When the prisms are adjusted for angle of minimum deviation, the spectrum of a star will be thrown about 7°.5 toward the central line of the apparatus. This will bring the two spectra close together on the photographic plate, $E\ F$, but in reverse order.

The plate being inclined 7°.5 to the axis of each telescope, the more refrangible rays in each case will have the longer distance to traverse before reaching the plate. Experiments made by the writer at Arequipa, with the 13-inch Boyden telescope with battery of two objective-prisms, showed that inclined plate-holders, one of 5°, the other of 10° inclination, gave a more extended region of sharp definition than when the plate was perpendicular to the telescope's axis. The focal distance was greater for rays of greater refrangibility. The mean of these two inclinations, or 7°.5, was thus used in Fig. 1.

Two smaller lenses of equal or greater focal length than the main objectives would be placed in the central line of the apparatus, one, L^3, to use as a guiding telescope, the other, a photographic lens, L^4, to give a reference image or trail of the star on the plate. Approximate positions of the lenses and prisms, as seen from the direction of the star, are shown in Fig. 2.

Flexure of the telescope tube from the great weight of prism cells and counterpoises, and the non-symmetrical form necessary, have been serious obstacles to close investigation with objective-prisms. By placing two systems in the symmetrical relation proposed, it is believed that torsion may be eliminated. Then results such as

Professor Bailey obtained for the spectroscopic binary μ^1 *Scorpii*, where both components are bright, might also be obtained with single stars showing motion.

The lenses and prisms arranged as in Fig. 1 would be firmly supported in a triangular box-shaped tube, represented in section

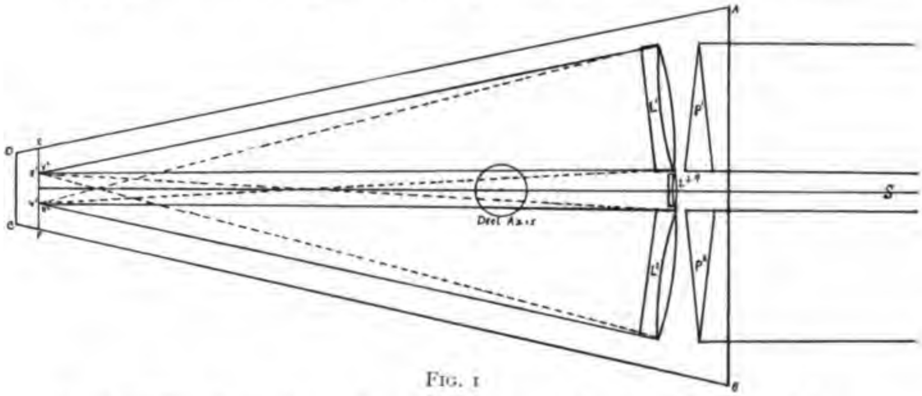


FIG. 1

by *ABCD*. This box-tube should be made of such material as to reduce variations from change of temperature to a minimum, and be so thoroughly braced as to avoid flexure. As it forms the whole telescope and not merely an eyepiece attachment, no sacrifice of weight is called for. It is intended to be bolted to the declination axis of an equatorial mounting in place of the regular telescope tube, or supported between the forks in the other style of mounting.

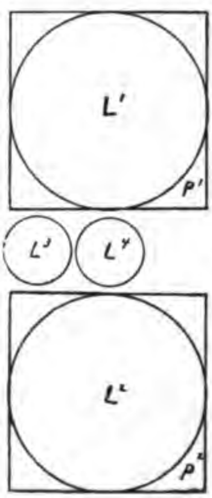


FIG. 2

In the figure the ratio of diamteter of principal lenses to focal length is large, being 1:5. It was so drawn to show how wide an angle the objectives could have and not interfere with the smaller lenses. Greater proportional focal length would have its advantages.

Experiments would show how the angle of separation should be changed to meet the conditions of the problem. Lenses 12 inches in diameter and of 15 feet focal length would allow room between them for a 4-inch auxiliary lens, if placed so that their centers

were 18 inches apart. This would mean 8° separation, and would require prisms of about 6° angle, whose minimum deviation would equal the necessary 4°. The same lenses could be used with prisms of any angle up to 25° or 30°, without losing the advantage of the inclination of the plate, or having the instrument become unwieldy through too great spread in declination. In any case, the minimum deviation of the prisms will need to equal one-half the angle of separation, which also equals the inclination of the plate to each prism-system. An increase of separation to 60° would call for 42° prisms, and would make the box-tube equilateral, thus nullifying the effects of expansion of the tube on the shifting of the spectra. Such a form would seem unmanageable unless of quite short focus, but its prisms would give large dispersion. It would hardly be possible to take full advantage of great focal length, large dispersion of prisms, and plate inclination in one instrument. Some middle course would be necessary.

In planning the instrument, its use for one star at a time was primarily considered. One *reliable* determination of a star's motion from each exposure should not be discouraging. When the problem is successfully solved for this most favorable position, then some further results might be looked for from other parts of the plate. The inclination of the plate might complicate the reductions for stars much removed in declination from the plate center.

Adjustment screws would be provided for lens and prism-cells, so that the two spectra and reference trail may be as favorably located as possible for plate measurement. This trail would be relatively stationary, while the spectra would show equal shiftings in declination, if the prism-systems were identical, or perhaps slightly unequal shiftings under actual working conditions. The trails or star-images make the negative virtually a chart-plate, whose constants may be fully determined, if necessary. These constants would serve to detect changes in focal length from temperature variations or other causes. Any shifting due to the star's motion would be doubled in quantity, and its amount would be finally determined differentially from measures of all suitable lines.

Careful "following" with lens L^3 would eliminate drift in declination, and proper width could be given to the spectra by changing

the rate of the driving-clock, or moving a right ascension micrometer-wire at a previously calculated rate.

In studying the problem it seemed essential that a form of instrument be used with which the two spectra shall be photographed simultaneously, so as to eliminate or equalize the differential effects of refraction, change in temperature, and flexure. This also means that the exposure time will be reduced one-half. The readjustment of an essential part of the spectrograph between the exposures, as the reversal of a prism or the plate, might make the results questionable and should be avoided. This calls for a duplication of some parts. A study of the peculiarities of any prism or lens may thus be made by interchanging its place.

Professor E. B. Frost, to whom my thanks are due for very kindly suggesting some of the difficulties of the problem, states that he would expect the probable error of a determination with this apparatus to be not less than 20 kilometers.

However, the plan suggested seems to meet many of the conditions of the problem. As actual work on the apparatus progressed, ways, optical and mechanical, might be found for overcoming the remaining obstacles.

CINCINNATI OBSERVATORY,
May 4, 1906.

SUN-SPOT LINES IN THE SPECTRA OF RED STARS[1]

By George E. Hale and Walter S. Adams

In a paper on "The Spectra of Stars of Secchi's Fourth Type" (*Publications of the Yerkes Observatory*, 2) the following statement appears on p. 129:

> The possibility that spots like those on the Sun may form a characteristic feature of fourth-type stars is strongly suggested by the evidence which we have accumulated (p. 123). It is hardly necessary to say, however, that much more evidence in this direction is needed. In view of the ease with which sun-spot spectra may be observed with instruments of moderate size, our knowledge of the widened lines is surprisingly meager. Much systematic work on spot spectra must therefore be done before the data desired for a thorough study of the question will become available. If the lines widened in sun-spots are to be regarded as characteristic of fourth-type stars, they seem to be equally characteristic of stars of the third type. This fact will permit a rigorous test of the identification of the lines to be made, since several stars bright enough to be photographed with very high dispersion occur among the stars of the third type.

Dr. Walter M. Mitchell has recently taken up this subject,[2] with the aid of his excellent observations of spot spectra, made with the Princeton refractor. He finds it almost impossible to make a satisfactory comparison of fourth-type and spot spectra, but concludes that they are not similar and that many spot lines are not represented in these stars.

The view suggested in the paper first quoted was not that fourth-type and spot spectra are similar, but rather that there was reason to suspect the presence in these stellar spectra of a considerable number of characteristic spot lines, which, if present, would presumably be due to large spots similar to those on the Sun. The presence in fourth-type spectra of strong lines and bands, such as the carbon flutings, which are known to be unaffected in sun-spots, is in no wise opposed to such a view. Indeed, these flutings are merely what may be expected to appear in a star like the Sun when it reaches an advanced stage of development.

The possibility, however, of comparing Dr. Mitchell's spot lines

[1] *Contributions from the Solar Observatory*, No. 8.

[2] *Astrophysical Journal*. 23, 211, 1906.

with those of the fourth-type stars throws new light on the subject, though it must remain in an unsatisfactory state until better photographs of fourth-type spectra can be obtained. Our five-foot reflecting telescope, when erected on Mount Wilson and provided with a suitable spectrograph, should be an ideal instrument for this research. At present we are able to contribute only such results as have been obtained with the Snow telescope, which is not adapted for work on stars as faint as those of the fourth type. So far as these latter stars are concerned, we limit ourselves for the present to recalling the probability that some of the missing spot lines in their spectra may be covered by bright lines. The rest of the evidence must stand as it is until better data become available.[1]

In order to secure material for an adequate determination of the wave-lengths of the lines in the spectrum of a third-type star, a plate of *α Orionis* was taken with the Snow telescope. The apparatus employed was a 64° prism of dense flint glass belonging to the five-foot spectroheliograph, used in conjunction with two visually corrected lenses of 5 inches (12.7 cm) aperture and 149 inches (3.78 m) focal length. The prism was sufficiently high to admit the full vertical aperture of the lenses, but in a horizontal direction could utilize a beam only 2.25 inches (5.72 cm) in width. The prism was set at minimum deviation for λ 5600. The whole instrument was inclosed in a box on the large pier inside the constant-temperature room of the Snow telescope house, and its temperature was accurately controlled by an ether regulator acting on a relay in such a way as to open and close automatically the circuit of heating coils inside the box.

It had been intended to expose the plate for two nights, but on the second night clouds cut the exposure short at the end of two hours.[2] The total exposure time was about seven hours, and the plate is not sufficiently strong to be of the best quality. It is, how-

[1] Of the four titanium lines referred to by Dr. Mitchell (p. 218), two are not in the "yellow region" to which my remark was limited (λ 5899.5 being beyond the reach of our three-prism plates); λ 5219.8, which was by some accident omitted from our tables of widened lines in spot spectra (*Contribution* No. 5), may be covered by a bright line in the stars (see p. 103 of our memoir); and λ 5471.4 is shown by our photographs to be one of the less conspicuous spot lines, ranging in intensity from 1 to 2.

[2] The rainy season prevented further work on the spectrum of *α Orionis*.

ever, measurable from about λ 5400 to λ 5700, and the results given in the table below are derived from it. The linear scale at λ 5400 is about 1 mm = 10 Ångströms.

The estimates of intensity are based upon Rowland's scale and are subject to some uncertainty, owing to the character of the plate. Reference lines were secured by taking certain of the lines referred to by Keeler as of the same intensity in the star and in the Sun, and using Rowland's intensities for these.

RADIAL VELOCITY OF *α Orionis*

λ in Sun	Intensity in Star	Intensity in Sun	Intensity in Spots	Velocity
5405.989	8	6	8	+53.58
5434.740	7	5	6	55.34
5447.130	8	6	8	52.19
5497.735	8	5	6	51.65
5501.683	6	5	5	54.34
5507.000	6	5	7	54.23
5569.848	5	6	6	51.75
5573.075	7	6	6	55.69
5576.320	4	4	4	55.44
5586.991	5	7	8	54.74
5624.769	4	4	4	54.38
5709.601	8	5 5	7 5	52.57
			Mean	+53.82
			Reduction to Sun	−27.16
			Radial velocity	+26.7 km

The wave-lengths given in the following table have been corrected for radial velocity:

LINES IN THE SPECTRUM OF *α Orionis*

λ in *	λ in ⊙	Element	Int. in *	Int. in ⊙	Int. in Spots	Remarks
5393.36	5393.38	*Fe*	6	5	5-6	
5394.88	5394.84 .91	*Mn*	7	1 1	4	
5407.62	5407.59 .69	*Mn*	3	0 0	2-3	
5409.95	5410.00	*Cr*	6	4	6	
5418.99	5418.98	*Ti?*	5	1	n.c.	
5420.59	5420.51 .61	*Mn*	4	0N 0N	3	
5426.50	5426.47	——	5	00	2	*Ti.* Hasselberg has 5426.48
5432.96	5432.75 33.16	*Mn* *Fe*	5	1 2	3 n.c.	
5436.85	5436.80	——	2	1	2	Possibly *V*

LINES IN THE SPECTRUM OF α *Orionis*—*Continued*

λ in *	λ in ⊙	Element	Int. in *	Int. in ⊙	Int.in Spots	Remarks
5442.60	5442.63	*Cr*	2	00	0	
5460.74	5460.72	——	5	00	2-3	*Ti*. Hasselberg has 5460.72
5470.88	5470.80 .88	*Mn*	4	0 0	2-3	
5490.62	5490.37 90.90 91.04	*Ti* —— ——	9	0 0 000	3 1-2 1-2	*Ti*. Hasselberg has 5490.88
5493.67	5493.71	*Fe*	3	1	1-2	
5504.12	5504.12	*Ti*	2	0	1	
5512.92	5412.47 12.74 13.20	*Fe* *Ti* *Ca*	8	1 2 4	n.c. 3 n.c.	
5514.68	5514.56 .75	*Ti* *Ti*	7	2 2	2-3	
5517.00	5516.95 17.03	*Mn*	7	0 0	2	
5528.65	5528.64	*Mg*	7	8	n.c.	
5530.98	5531.00	*Ti*	2	00N	0-1	
33.05	5532.97 33.09	—— ——	6	1 0	n.c. n.c.	
5535.65	5535.64 .78	*Fe* ——	8	2 0	3-4	Rowland and Harrison have *V* line at 5535.66
5537.96	5537.93 38.02	*Mn*	3	00 00	2	
5546.82	5546.73 47.22	*Fe* *Fe, V*	5	2 1	2-3 1-2	
5565.77	5565.70	*Ti*	5	00	2	
5582.19	5582.20	*Ca*	5	4	5	
5584.77	5584.73	——	2	000	00	*V*. Rowland and Harrison have 5584.74
5594.72	5594.69 .88	*Ca* *Fe*	5	4 1	5 n.c.	
5598.67	5598.52 .71	*Fe* *Ca*	8	1 4	n.c. 5	
5626.24	——	——	3	——	1	*V*. Rowland and Harrison have 5625.27
5627.85	5527.86	*V*	4	00	2-3	
5641.67	5641.67	*Fe*	3	2	n.c.	
5644.30	5644.26 .37	—— *Ti*	3	00 0	2-3	
5664.86	5664.80	——	4	000	0	
5668.63	5668.59	*V*	6	000	1	
5675.60	5675.65	*Ti*	6	2N	2-3	
5682.86	5682.87	*Na*	7	5	7	
5698.79	5698.75	*V*	7	1	3-4	
5700.53	5700.51	*Cu?*	3	00	2-3	Probably *Sc*
5703.75	5703.80	*V*	5	1	3	

The intensities of the following iron lines, which could readily be identified from their coincidence with lines in the comparison spectrum, were also noted. They were not of suitable quality for the determination of radial velocity and so were not measured.

Line	Intensity in Star	Intensity in Sun	Intensity in Spots
5397.34	10	7	9
5404.36	7	7	7–8
11.11	4	4	n.c.
15.42	6	5	n.c.
24.29	6	6	n.c.
29.91	8	6	8
45.26	5	4	n.c.
55.67 } .83 }	6	6	n.c.
5615.52 } .88 }	9	8	n.c.

The abbreviation "n. c." denotes that the line is unaffected.

A summary of these results gives the following values for the difference between the relative rise of intensity in *α Orionis* and spots:

RISE IN INTENSITY

	Spots	*α Orionis*	*α Orionis*–Spots
Vanadium	2.5	5.0	2.5
Titanium	1.5	4.2	2.7
Manganese	1.3	3.7	2.4

The approximately constant value of *α Orionis*–spots indicates the great similarity in the behavior of these elements in spots and in the star.[1]

Of the individual lines affected probably the most interesting case is λ 5626.24. This line does not appear in Rowland's Preliminary Table, but is prominent in spots. It is almost certainly due to vanadium, which has a line of considerable intensity at λ 5626.27. Two other vanadium lines, λ 5584.73 and λ 5668.59, of intensity 000 in the Sun, and a third of intensity 00, are all important lines in the star. The cumulative evidence afforded by the

[1] In comparison with these values we have for ten lines of iron affected in spots and measured in *α Orionis* the following values of the rise in intensity as referred to the Sun:

Spots	*α Orionis*	*α Orionis*–Spots
1.1	1.1	0.0

behavior of these lines as to the similarity of the spectra of stars and spots is extremely strong, quite apart from the similar testimony afforded by the other lines of this element, as well as those of titanium and manganese. The last-named element, as was shown by Mitchell and confirmed by the observations of Hale and Adams, is one of the most prominent in the spectrum of spots.

Though it has not been possible, on account of the character of the plate, to measure all the lines which are present, the list given above affords very strong evidence of the general agreement between the spectrum of *a Orionis* and that of sun-spots. In the region covered, λ 5393 to λ 5704, there are but four spot lines of intensity greater than 1–2 on Rowland's scale that have not been measured in *a Orionis*, and these are all present but too diffuse for measurement. Of the fainter lines, several are practically obliterated in the band, the more refrangible edge of which falls at λ 5447.

In a comparison of the stellar lines with those affected in spots the greatest interest naturally attaches to the lines of the three elements most prominent in the latter—vanadium, titanium, and manganese. Including the almost certain identifications with the lines given in Rowland and Harrison's table of the arc spectrum of vanadium, we find in the region under discussion six lines with a mean rise in intensity in spots, as compared with the Sun, of 2.5. All of these lines are found in *a Orionis* and show a mean rise in intensity of 5.0. Identifying the titanium lines in a similar way with those of Hasselberg's table, we find nine lines due solely to titanium which are affected in spots and are of intensity greater than 1–2. One of these is not measured in the star, and three others blend with adjoining lines. The remaining five have a mean rise in intensity in spots of 1.5, and in *a Orionis* of 4.2. In addition, there are two lines of mean intensity 0.8 in spots, which are measured in *a Orionis.* Of manganese there are eight lines affected in spots. Of these one is not measured in *a Orionis*, and another forms a blend. The remaining six show a mean rise in intensity in spots of 1.3, and in *a Orionis* of 3.7.

SOLAR OBSERVATORY,
Mount Wilson, May, 1906.

Minor Contributions and Notes

NOTE ON THE *ALGOL* SYSTEM

In the case of variables of the *Algol* type it is well known that an upper limit to the mean density of the system can be found.[1] Also in the case of *Algol* itself, where we know the velocity of one component, the dimensions of the system can be calculated if we make such an assumption as that the densities of the two components are equal;[2] but it does not seem to have been remarked that without any such assumption a lower limit to the diameters can be obtained, and also upper limits to the density of each component separately.

If we call

a, a', the radii of the two components,
r, r', the radii of their orbits,
d, d', their densities,
T, the period of revolution,
t, the duration of light-variation,
γ, the constant of gravitation,
D, the mean density,

then, calculating for a circular orbit and central eclipse, which will be sufficiently accurate throughout this paper, we find

$$D=\frac{3\pi}{\gamma T^2}\cdot\frac{(a+a')^3}{a^3+a'^3}\cdot\frac{1}{\sin^3\frac{\pi t}{T}}\,.$$

If we put

$$a'=0.764\,a,^3$$
$$t=9^{\mathrm{h}}\,20^{\mathrm{m}},$$

we find
$$D=0.129\,.$$

We have also $a+a'=(r+r')\sin\dfrac{\pi t}{T}$, and if we write

$$d'=nd\,,\quad a'=ka\,,\quad (k=0.764)$$

[1] Alexander Roberts, *Astrophysical Journal*, 10, 308, 1899; H. N. Russell, *Ibid.*, 10, 315, 1899.

[2] H. C. Vogel, *Astronomische Nachrichten*, 123, 289, 1890

[3] E. C. Pickering, *Proc. Amer. Acad.*, 16, 27, 1881.

we can deduce

$$a=r\frac{nk^3+1}{nk^3(k+1)}\cdot\sin\frac{\pi t}{T},$$

$$d=D\frac{k^3+1}{nk^3+1},$$

$$d'=D\frac{n(k^3+1)}{nk^3+1}.$$

Consequently we find that a is a minimum when n is infinite and that then

$$a=0.234\,r.$$

Hence, r being a million English miles, 468,000 is a lower limit to the diameter of the bright component. There is no upper limit; the smaller n is, the larger must the diameters be, supposing, of course, the eclipsing body to be always opaque and faint in comparison with the bright one.

Again, d is a maximum when $n=0$, and then $d=0.186$; d' is a maximum when n is infinite, and then $d'=0.418$; the maximum of d occurring when $d'=0$ and conversely.

While the ratio of the densities is not likely to be a very large number, yet, on the other hand, it may differ considerably from unity, and the following results have been calculated for densities of the satellite ranging from four times to one-fourth that of the primary:

$\frac{d'}{d}$	$\frac{a}{r}$	$\frac{r'}{r}$	d	d'	m	m'
4	0.36	0.56	0.07	0.27	0.029	0.052
2	0.50	1.12	0.10	0.20	0.107	0.096
1	0.76	2.24	0.13	0.13	0.51	0.23
0.5	1.28	4.48	0.15	0.08	2.84	0.63
0.25	2.33	8.96	0.17	0.04	19.2	2.14

The second column practically gives the radius of the larger body in millions of miles. The last two columns give the masses of the two in terms of the Sun's mass.

A much greater diameter and smaller density are given here for the case of equal densities than are given by Vogel. This is, of course, due to taking t as $9^h\,20^m$ instead of $6^h\,30^m$.[1]

R. J. A. Barnard.

Melbourne.

[1] See Vogel, *loc. cit.*

LETTER FROM PROFESSOR CALLENDAR

With reference to my letter of October 26, 1905, which appeared in the March issue of your *Journal*, I have since had the pleasure of a personal interview with Mr. G. T. Walker, which has resulted in a simple explanation of the difficulty experienced with the sunshine receiver in question. Mr. Walker informs me that there was a good deal of condensation inside the cover of the receiver at the time when he saw it, which would naturally render the results unreliable, but that there was no drying material in use at the time, and that neither he himself nor the observer in charge was aware of the necessity of employing drying material to prevent condensation. It appears on investigation that the instrument company which supplied the receiver, by some accidental oversight, owing to the different parts of the apparatus having been ordered and supplied at different times, omitted to send specific instructions with regard to the necessity of employing drying material in the receiver. I greatly regret that this omission did not come to my knowledge sooner. but I had no personal knowledge of the transaction, and the instrument company had some difficulty in finding the records of the correspondence, etc., relating to the subject, as the instrument was supplied so long ago. Mr. Walker assures me that he has no reason to believe that the method would not give good results if the receiver were kept dry, but he agrees with me that the hermetically sealed type would be more suitable for use in damp climates, as requiring less attention; though even in this case it is necessary to clean the exterior of the receiver at frequent intervals, if exposed to dust or damp. As several of these instruments are now in use in various parts of the world for investigating possible variations of the solar radiation, it is important to draw attention to the necessity of these precautions, as other observers may have experienced similar difficulties.

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